NASA CR-191036

Orbital Transfer Vehicle Oxygen Turbopump Technology

Contract NAS 3-23772

Test Series F&G
Task B.8 Final Report

Volume III – Hot Oxygen Testing

October 1992

Prepared by:

Robert L. Urke

RLU 3/25/93

Prepared for:

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

NASA
National Aeronautics and Space Administration

REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-191036		

4. Title And Subtitle	5. Report Date
Orbital Transfer Vehicle Oxygen Turbopump Technology Final Report, Volume III – Hot Oxygen Testing	October 1992
	6. Performing Organization Code
7. Author(s) R.L. Urke	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address Aerojet Propulsion Division P.O. Box 13222 Sacramento, CA 95813	11. Contract or Grant No. NAS 3-23772
	13. Type of Report and Period Covered 7-17-89-12-31-89
12. Sponsoring Agency Name and Address NASA/Lewis Research Center Cleveland, Ohio 44135	14. Sponsoring Agency Code

15. Supplementary Notes

NASA/Lewis
M. Proctor Technical Monitor

16. Abstract

This report covers the work done in preparation for a liquid oxygen rocket engine turbopump test utilizing high pressure hot oxygen gas for the turbine drive. The turbopump (TPA) is designed to operate with 400°F oxygen turbine drive gas. The goal of this test program was to demonstrate the successful operation of the TPA under simulated engine conditions including the hot oxygen turbine drive. This testing follows a highly successful series of tests pumping liquid oxygen with gaseous nitrogen as the turbine drive gas. That testing included starting of the TPA with no assist to the hydrostatic bearing. The bearing start entailed a rubbing start until the pump generated enough pressure to support the bearing. The articulating, self-centering hydrostatic bearing exhibited no bearing load or stability problems. The TPA was refurbished for the hot gas drive tests and facility work was begun, but unfortunately funding cuts prohibited the actual testing.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Oxygen turbopump; hydrostatic bearings; Expander cycle engine, Cryogenic propellant pumping; Hot Oxygen Gas Turbine Drive	Unclassified Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	85	

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FOREWORD

This document represents a final report to the National Aeronautics and Space Administration for work performed under Test Task Order B.8 to Contract NAS 3-23772. The task work span was from 17 July 1989 to 31 December 1989.

The tests reported herein are Series "F and G" of a planned test to verify the operation of a gaseous oxygen driven turbine powering a liquid oxygen pump. No interpropellant seals or purge gas are required for this concept.

Volume I of this report covered the turbopump design, fabrication, and Series A and B testing. Volume II covered the Nitrogen and Ambient Oxygen Testing, Test Series C, D, and E. This volume, Volume III, is supposed to report on the testing with 400°F oxygen turbine drive which will duplicate the expected operating conditions.* However, due to insufficient funding, testing was postponed.

* The Series "F" testing was originally proposed with the intent to use a new Aerojet hot gas test facility. However, the facility could not be made available until after the expected completion of the OTV program. The selected alternative was to modify an existing test bay at the White Sands Test Facility.

ORBITAL TRANSFER VEHICLE OXYGEN TURBOPUMP TECHNOLOGY

FINAL REPORT, VOLUME III HOT OXYGEN TESTING

Prepared By:

Robert L. Urke

SUMMARY

This report documents the continuation of testing of a rocket engine turbopump assembly (TPA) designed to supply high pressure liquid oxygen propellant to the engine. This TPA is unique in that it uses hot (400°F) gaseous oxygen as the turbine drive fluid. It is a critical technology for the dual propellant expander cycle, a cycle using both hydrogen and oxygen as the working fluids for a maximum performance cryogenic propellant rocket engine.

The first volume of this report (Reference 1) documents the results of earlier NASA LeRC funded work to determine the structural materials most compatible with liquid and 400°F oxygen and the detailed design of the turbopump using these materials. It also has a discussion of the TPA fabrication and the Series A and B tests which verified the hydrostatic bearing concept in a bearing tester using many common parts from the TPA. These tests successfully demonstrated the hydrostatic bearing system at speeds up to 72,000 rpm in liquid nitrogen. Following these tests, the housing and rotating assembly turbine impellers were finish machined to form a complete oxygen TPA. Difficulties in finding a competent machine shop willing to bid on this finish machining caused the start of the next series of tests to be delayed well over a year. The test series documented in Volume II (Reference 2), Series C, D, and E, started on 15 February 1989 and were concluded on 21 March 1989.

Series C1 used liquid nitrogen in the pump and gaseous nitrogen as the turbine drive gas. Series C2 used liquid oxygen as the pumped fluid with gaseous nitrogen driving the turbine. The TPA performed as expected with limitations on the turbine speed due to the use of nitrogen as the turbine drive fluid which has a lower density than that of oxygen. In addition, the drive gas temperature was lower than design temperature and the flow passage resistance was higher than expected.

Series D also used gaseous nitrogen drive while pumping liquid oxygen, but the starts were made without any prepressurization of the hydrostatic bearings using the separate bearing assist supply. This is a realistic condition for actual engine operation, and results in a rubbing start. When the drive pressure exceeded the "breakaway" force the rotating assembly accelerated normally.

Test Series E1 demonstrated the pure gaseous oxygen turbine drive with LOX in the pump. This was done with the bearing assist system on. Series E2 again used an ambient oxygen turbine drive but the bearing assist system was off, and the hydrostatic bearing system provided its own pressurization after a rubbing start.

Total operating time during the testing was 2268 seconds. The test article had 14 starts without bearing assist pressurization. Operating speeds of up to 80,000 rpm were logged (Test 135) with a steady state speed of 70,000 rpm (Test 165) demonstrated.

The hydrostatic bearing system performed satisfactorily exhibiting no bearing load or stability problems. Post test examinations of the journal and thrust bearing surfaces showed minor evidence of operating wear. The silver plated bearing surfaces showed some smearing from rubbing and one gouged area apparently due to a particle passing through the bearing. No monel surfaces were exposed by the silver plate wear. There was no evidence of any melting or oxidation due to the oxygen exposure. There was one minor anomaly encountered that was not traced to a particular cause. This was a slow axial motion, sinusoidal at 10,000 cpm, (≈167 Hz) of ±0.0005 inch amplitude. It caused no problems during the testing but was plainly evident in the distance readings from the axial probe.

The conclusion of Series C, D, and E testing made the turbopump hardware available for refurbishment prior to continued testing.

In general, the pre-test coordination work was completed prior to the termination of the Task Order. The Task Order Work Plan was generated, Test Plan completed and the TPA hardware was refurbished. The TPA was not assembled however, the housing was sent to WSTF for stand mock-up and addressing of the proximity probe issues had begun. A more detailed treatment of the status of the work accomplished is described in Section 2.0

1.0 INTRODUCTION

1.1 BACKGROUND

This oxygen turbopump test program supports the NASA-OAST plans for development of a new orbit transfer vehicle (OTV) to be operational in the late 1990s. Critical to the economical operation of a space based OTV is a new O_2/H_2 rocket engine with capabilities superior to existing engines. Table 1 presents the technology goals for the new OTV engine. It summarizes the characteristics of the production RL-10 reference engine and those desired in a new engine. In total, these requirements represent a substantial advance in the state-of-the-art, and a considerable challenge to rocket engine designers. Aerojet Propulsion Division has selected a unique engine cycle and turbopump designs in response to those requirements. The result is an advancement in the state of the art that combines a heated oxygen driven turbine with a long life hydrostatic bearing system to yield an advanced, high performance oxygen turbopump.

1.1.1 Aerojet Dual Expander Cycle

In a conventional (single) expander cycle engine hydrogen is routed through passages in the combustion chamber where it cools the wall and acquires thermal energy to power the turbine of both hydrogen and oxygen pumps. It is then routed to the injector for combustion. This cycle is fairly simple, and it offers good performance potential as all propellant is burned in the combustion chamber. It does not have the losses associated with open cycles. Its limitations are related to dependence on only one propellant as a turbine drive fluid which, in turn, requires interpropellant seals and purge gas for the oxygen turbopump. To obtain the needed power the hydrogen must be heated to a temperature very near to the design limit for the copper based alloys employed for the chamber liner. With the added limits imposed by the high number of starts, long operating times without maintenance, and a 10:1 or greater engine thrust throttling requirement, the hydrogen expander cycle is capable of only modest performance and life improvements over the production RL-10 engine.

The Aerojet dual expander cycle alleviates these limitations by using oxygen as a working fluid as well as hydrogen. This reduces the demands on the hydrogen circuit as the oxygen turbopump is driven by heated oxygen. It also eliminates the need for an interpropellant seal and the associated helium purge system weight penalty. The oxygen is heated to approximately 400°F by flowing through a LOX/GH_2 heat exchanger and then through the regeneratively cooled nozzle extension. The flow schematic is shown in Figure 1. The hydrogen used

TABLE 1

TECHNOLOGY GOALS FOR THE NEW OTV ENGINE

Parameters	Reference Engine System Characteristics	October 1986 NASA Goals and/or Requirements	1988 Updated Goals or Requirements
Basing	Earth	Not Specified	Space
Human-rating	No	Not Specified	Yes
Safety Criteria	Not Specified	Not Specified	Fail Operational, Fail Safe
Propellants - Fuel	Hydrogen	Hydrogen	Hydrogen
- Oxidizer	Oxygen	Oxygen	Oxygen
Vacuum Thrust (Design Point)	15,000 lbf	10,000 - 25,000 lbf*	7500 lbf (per engine)
Number of Engines per Vehicle		Not Specified	2 Minimum
Engine Mixture Ratio, O/F (Design Point)	5.0	6.0	6.0
Engine Mixture Ratio Range, O/F	4.4 to 5.6	5 - 7	5 - 7
Propellant Inlet Temperature -			
Hydrogen	38.3°R	37.8°R	37.8°
Oxygen	175.3°R	162.7°R	162.7°R
Gimbal	±4.0 Degrees	±6.0 Degrees (Sq. Pattern)	±20 degrees Pitch & Yaw
Aerobraking Design Criteria	The engine must be compatible with aeroassist return of the vehicle to low-earth orbit.		
Vacuum Specific Impulse	444 lbf-sec/lbm	520 lbf-sec/lbm	490 lbf-sec/lbm
Vacuum Thrust Throttling Ratio	No Throttling	30:1	10:1
Net Positive Suction Head (NPSH) -			
Hydrogen	133.0 ft-lbf/lbm	0	15 ft-lbf/lbm
Oxygen	16.7 ft-lbf/lbm	0	2 ft-lbf/lbm
Weight	290 lbm	360 lbm	360 lbm (2 engines)
Length	70.1 in.	40	TBD (Assume 60", Stowed)
Reliability (90% Confidence Level)	0.9982	1.0	.9975 Single engine, .99958 Dual engine**
Operational Life	3 Starts, 4000 sec	500 Starts, 20 Hours	500 Starts, 20 Hours
Service Free-Life		100 Starts, 4 Hours	100 Starts, 4 Hours
Start Cycle		Chilldown with propulsive dumping of propellants, tankhead start, pumped idle operation, autogenous tank pressuration required	

Updated 1 March 1990

*Vehicle engine set total thrust must be in this range

**MSFC/Boeing Vehicle Studies

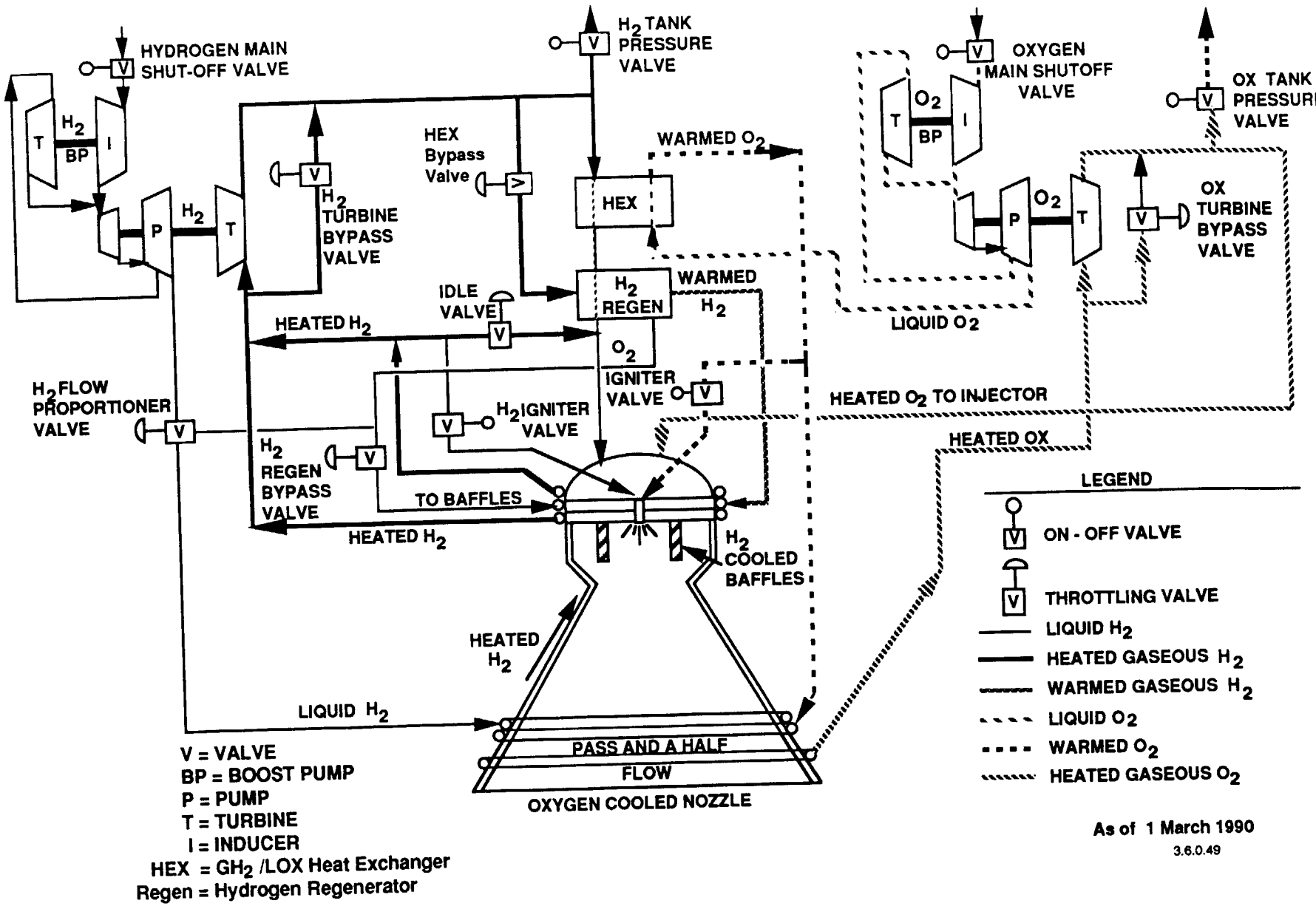

Figure 1. Dual Expander Cycle Schematic

to heat the cold oxygen in the heat exchanger is the effluent from the hydrogen TPA turbine. It provides the thermal energy to the oxygen at a thermodynamic cost to the hydrogen circuit due to the pressure drop across the heat exchanger. Also, both propellants are delivered to the thrust chamber injector as superheated gases; an important aid to combustion stability over a wide throttling range.

1.1.2 Oxygen Turbopump

Key to this turbopump design is the use of a hot oxygen turbine drive. Many turbopumps have been successfully used to pump liquid oxygen, but hot oxygen has been considered too reactive to use as a turbine drive fluid. The NASA LeRC has sponsored an extensive program in oxygen compatibility experiments with various materials and under various conditions of pressure, temperature, and mechanical stress. A number of materials have been identified that can be used in an oxygen turbopump with high confidence that the materials will not ignite under either particle impact or minor rubbing at temperatures in the 400°F range. Despite the experimental data, verification of an oxygen turbopump requires successful completion of an extensive test program in which the TPA will have demonstrated compatibility of the selected materials with cryogenic oxygen, ambient oxygen, and 400°F oxygen in conditions closely approximating actual service.

The oxygen TPA also uses a number of design innovations other than materials selection. The most critical is the self aligning hydrostatic bearing system. The long life requirements of the OTV engine are incompatible with conventional ball bearing systems that require rolling and sliding contact in liquid oxygen at high speeds. A hydrostatic bearing was chosen for this TPA as it had the potential for very long service life free of wear or fatigue life limits.

The oxygen turbopump consists of a single stage full admission axial flow turbine that drives an inducer and a two stage centrifugal pump, Figure 2. The centrifugal pump impellers face in opposite directions utilizing the back hub as part of the axial thrust bearing. A journal bearing is integral with and between the thrust faces. A second journal bearing, located between the pump and turbine, carries radial load only. Both bearings are hydrostatically supported to permit self-alignment. Maximum bearing capacity is achieved with parallel alignment. The inducer permits full speed operation down to a minimum Net Positive Suction Heat of 20 ft-lbf/lbm of liquid oxygen. An additional 17.3 gpm capacity is designed into the inducer.

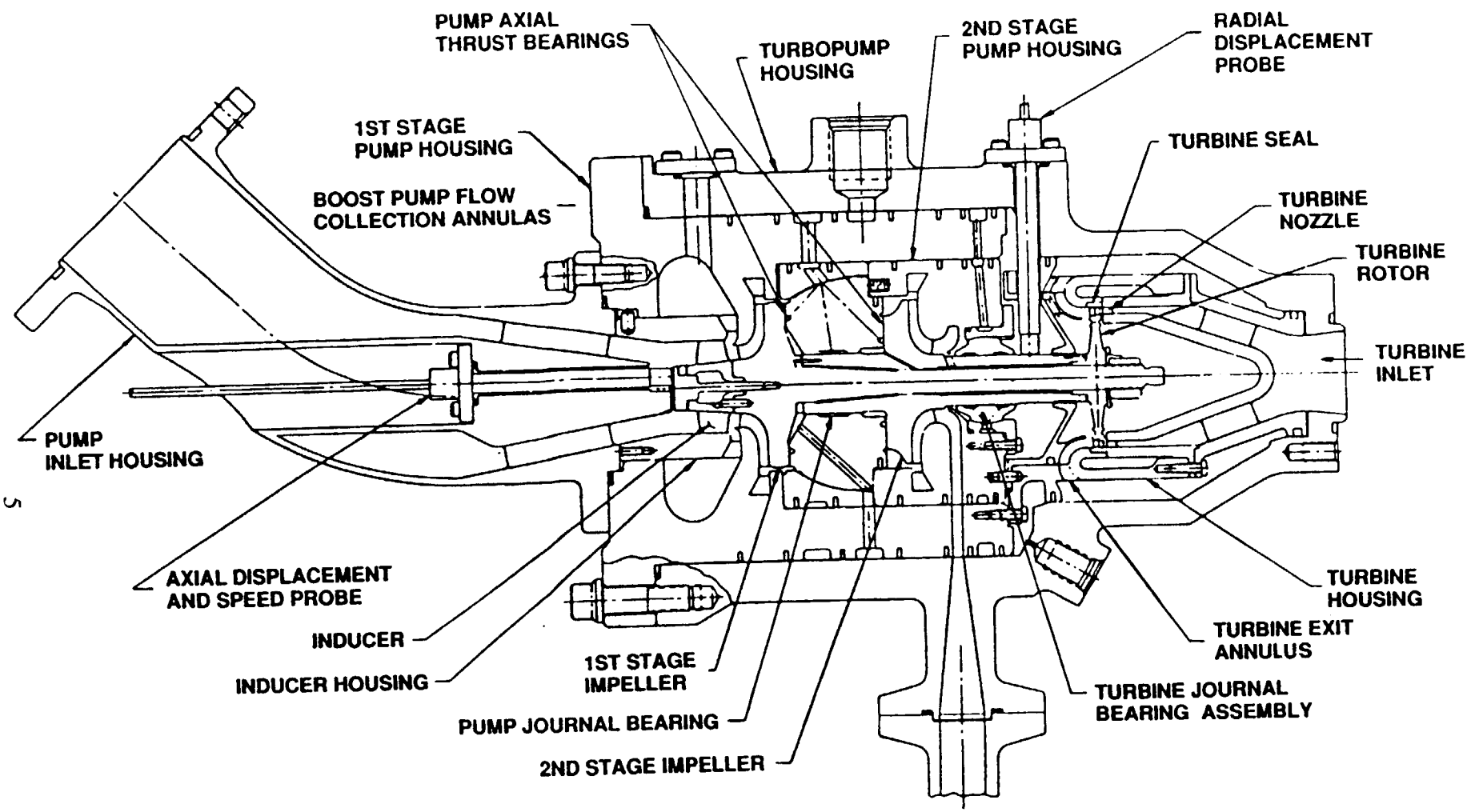

Figure 2. OTV Oxygen Turbopump Assembly

1.1, Background (cont.)

This flow is turned radially before the first stage centrifugal impeller and is collected in an annulus to then be conveyed to a boost pump hydraulic turbine.

A boost pump, not part of this contract, will be required to meet the 2 ft. lbf/lbm minimum Net Positive Suction Head at 162.7°R when flowing liquid oxygen, Table 1. The 156 shp turbine powers the pumps at 75,000 rpm delivering 34 gpm through-put at 4600 psi pressure rise. Complete design specifications are discussed in Reference 1.

This document constitutes the test report on the Orbital Transfer Vehicle (OTV) oxygen turbopump for that portion of the design verification testing using 400°F oxygen as the turbine drive gas. This is series 'F' in a test program that began in 1987.

At this point in the program test series E_2 has been completed using ambient gaseous oxygen for the turbine drive fluid. The testing covered in Series 'F' will extend the experience base to higher temperature (400°F) gaseous oxygen turbine drive gas. The Series 'F' tests will utilize the actual service fluid, 400°F gaseous oxygen, as the working fluid in the turbine and LOX in the pump circuits, providing a true simulation of operating conditions. The turbopump will accumulate additional operation time, demonstrate numerous start/stop cycles, and demonstrate additional hydrostatic bearing operation without prepressurization (lift-off). Tear down and examination of the TPA will complete the Series 'F' test series.

An optional extension to the testing, designated Series 'G', would add thermal margin tests. In Series 'G' the temperature of the turbine drive gas would be raised to 425°F, 450°F, 475°F, and 500°F in four separate tests. A teardown inspection would follow with particular attention to surfaces for any indication of thermal effects or degradation.

This testing which was to be done at the NASA White Sands Test Facility, was postponed due to funding.

1.2 OBJECTIVES

The fundamental objective of the OTV oxygen turbopump test program is to identify and develop the pertinent technology for operating a high pressure LOX pumping/GOX driven turbopump for extended duration with multiple start/stop cycles. The main technology issue is the ignition potential from a metal rub or particle impingement in pure oxygen service. The overall goal is to provide extended life and restart capability. The main thrust of the test

program is to demonstrate the viability of this design approach for high-speed LOX/GOX turbopumps, and to develop a data base in this area.

Specific test objectives for the testing, are outlined here with a brief discussion of each.

1. Demonstrate operation with 400°F gaseous oxygen driven turbine – Previous testing will have been performed with GN_2 and ambient-temperature gaseous oxygen. For this test, oxygen gas at a temperature of 400°F (nominal) will be used.

   The intent is to demonstrate safe operation free of ignition from material reaction, particle impingement, or rubbing friction at this higher temperature.

2. Demonstrate additional starts without bearing assisted liftoff. – This will validate the hydrostatic bearing durability in normal engine start conditions (400°F oxygen in the turbine). A total of 100 starts is desired.

3. Accumulate maximum operating time at rated speed – Four hours is desired to meet the design goal for the OTV oxygen turbopump. Facility limitations and test cost will determine the actual operating time and speed.

4. Demonstrate Thermal Margin (Optional) – Conduct four tests with turbine drive gas at 425, 450, 475, and 500°F, respectively, to demonstrate thermal margin. conduct a thorough teardown inspection for evidence of any thermal degradation or damage after performing the 500°F test.

1.3 OUTLINE OF SCOPE OF WORK AND SUBTASKS

To support the objectives of the OTV program for this main task the following subtasks were established and work was begun. Aerojet was directed to use NASA's Johnson Space Center's White Sands Test Facility (WSTF) located in New Mexico for the heated GOX testing. Aerojet was to prepare the test article for installation, provide assistance in test readiness, and provide project engineer support during the testing.

1.3, Outline of Scope of Work and Subtasks (cont.)

1.3.1 Scope

The basic scope was to support the test program at WSTF to determine the performance and operation characteristics of the oxygen turbopump. This was to be done using heated gaseous oxygen (GOX) provided by WSTF facilities.

1.3.2 Subtask Descriptions

The following are the subtasks as defined by the customer at the onset of this phase of the program. These will be the baseline of the accomplishments for this report.

1.3.2.1 Subtask I – Task Order Work Plan

Within fifteen (15) working days after the effective date of this Task Order, the Contractor shall prepare and submit three (3) copies of the Task Order Work Plan to the NASA LeRC Task Order Manager. As a minimum, the Work Plan shall include the following.

a. A work schedule reflecting planned activity and major milestones necessary in achieving the requirements set forth in the Task Order Specifications.

b. A resource utilization plan showing estimates by month for the following:

Direct Labor Hours	(Subtask Level)
Direct Labor Dollars	(Subtask Level)
Material, Computer & Other Direct Costs	(Task Order Level)
Overhead	(Task Order Level)
General & Administrative	(Task Order Level)
Total Cost	(Task Order Level)

1.3.2.2 Subtask II – Turbopump Refurbishment

The Contractor shall evaluate the present condition of the LOX turbopump (following testing at ATS under Task Order NAS3-23772-B.7), and make any hardware modifications necessary to promote safe and reliable operation when the turbopump is driven by 400°F gaseous oxygen in the turbine. The Contractor shall submit all recommended modifications to the NASA LeRC Task Order Manager for review and approval prior to initiating any modifications.

1.3, Outline of Scope of Work and Subtasks (cont.)

The Contractor shall provide suitable protection for the refurbished turbopump during handling and shipping to the WSTF test site.

1.3.2.3 Subtask III – Pretest Coordination

The Contractor shall provide consultation and support to WSTF suitable to ensure a safe and efficient test setup.

The Contractor shall review the proposed WSTF test site and provide suitable design, analytical, or operational support necessary to assure test conditions for the turbopump consistent with previous test efforts, and to meet the desired 400°F gaseous oxygen fluid conditions for the turbine. To accomplish this, the Contractor shall develop a comprehensive OTV LOX turbopump Test Plan outlining the objectives and approach for completing the test program. This Test Plan shall be submitted to the Task LeRC Order Manager for approval prior to initiation of any testing.

1.3.2.4 Subtask IV – Series F Testing

The Contractor shall provide support to WSTF during the LOX turbopump testing in accordance with the NASA LeRC approved Test Plan. The Contractor shall provide suitable personnel to participate in any critical reviews prior to test initiation, and during all test activity involving TPA rotation.

1.3.2.5 Subtask V – Data Reduction and Analysis

All test data will be recorded by WSTF, as specified in the NASA LeRC approved Test Plan. WSTF will also apply any calibrations and reduce the data to engineering units specified in the Test Plan. The Contractor shall perform further data reduction and analysis suitable to characterize the turbopump performance. Specific data and format to be included in the Final Report shall be as mutually agreed to by NASA LeRC and the Contractor.

Following completion of the turbopump testing, the Contractor shall perform a disassembly and inspection of the turbopump hardware. The location of the site for carrying out this disassembly and inspection shall be as mutually agreed to by NASA LeRC, WSTF, and the Contractor.

1.3, Outline of Scope of Work and Subtasks (cont.)

The Contractor shall carefully document the results of the inspection, including photographs, measurements, and qualitative evaluations. All documentation of the inspection shall be included in the Final Report.

1.3.2.6 Subtask VI – Reporting and Task Management

The reports identified in Section I.B. of this Task Order shall be prepared and distributed in accordance with Exhibit A of Contract NAS3-23772. In addition, a final formal report will be submitted as a NASA Contractor's Report and will cover the refurbishment, testing, and post-test inspection accomplished under this Task Order. A draft final report shall be submitted to NASA LeRC within 30 days after completion of data reduction. In addition, a summary oral report shall be presented at NASA LeRC following completion of the testing.

2.0 SUBTASK STATUS

The following is a summary of the work accomplished on the various program subtasks.

2.1 SUBTASK I – TASK ORDER WORK PLAN

A task order work plan was generated and submitted in August 1989. The complete document is included as Appendix A. In summary, the plan describes the work required to prepare the hardware for test, test requirements and test objectives. The task in 1989 dollars was a $270K job spanning approximately one year.

2.2 SUBTASK II – TURBOPUMP REFURBISHMENT

As listed in the work plan, the following was to be done for:

Subtask 2 – TPA Refurbishment

Prior to shipping the turbopump to WSTF for installation, the following hardware modifications were made:

- Replate and remachine bore of turbine journal bearing
- Replate and remachine bore of pump journal bearing
- Replace "K" seals between MS fittings and turbopump housing
- Rework or replace speed/proximity probes
- Replace several #2 screws
- Chase threads in turbopump housing
- Modify face seal groove in turbine nozzle
- Fabricate one (1) additional set of external crossovers to:
  1) Remove mismatch between pipe and flange,
  2) Add pressure and temperature sensing instrumentation at both ends of the crossovers.
- Flow turbine nozzle to verify CdA
  - If area undersized, rework or replacement may be recommended, but will not be done as part of this effort.

2.2, Subtask II – Turbopump Refurbishment (cont.)

- Turbine Nozzle CdA Verification

This work was done and reported in the OTV Final Report Vol. II – Nitrogen and Ambient Oxygen Testing Report. The results are summarized in Figure 3 showing the data, both raw and curve fit data of a nitrogen cold flow test. From this data and physical measurements, the nozzle effected flow area coefficient Cl was derived. This data is shown in Table 2.

Table 2

Cold Flow Testing

	Nozzle Area, $in.^2$	Cd	CdA
Blueprint	.06559	.945	.06198
Measured	.06247*	.918	.0573

*Correction from Volume II (Reference 2).

2.3 SUBTASK III – PRETEST COORDINATION

A meeting was held at WSTF on 12 June 1989 to discuss the test, test set up and requirements. The general objectives of the program were discussed. These are as shown:

Series "F" Tests
Primary Objective

To demonstrate safe operation of the ATC oxygen TPA using 400°F oxygen as the turbine drive gas

Secondary Objectives:

- To validate the material's selection for the OX TPA
- To demonstrate TPA start-up under conditions similar to normal operation
- To demonstrate TPA transient performance under simulated engine throttling
- To accumulate running time prior to teardown assessment of the TPA mechanical condition

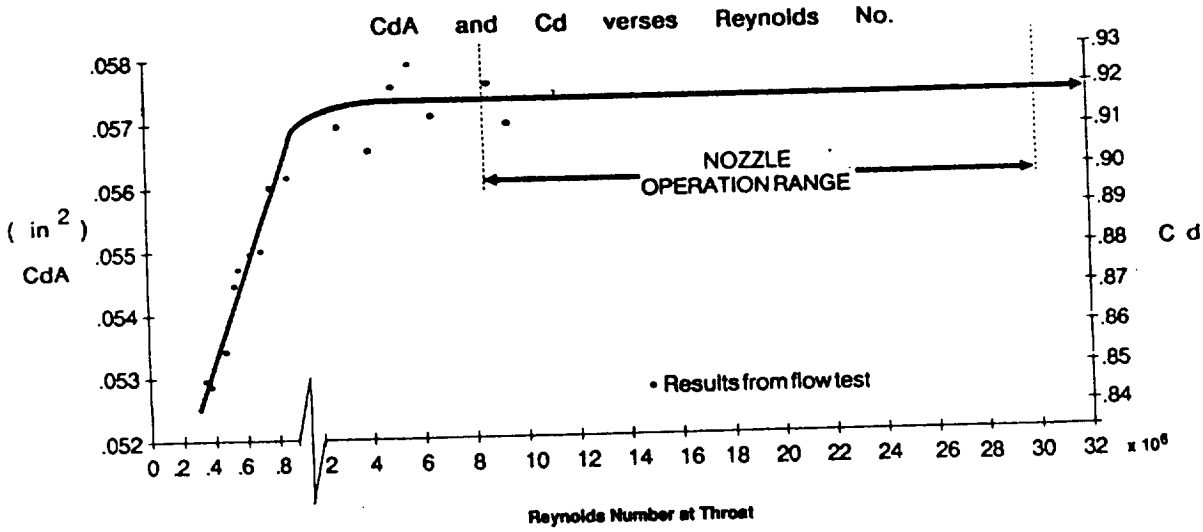

Figure 3. Nitrogen and Ambient Oxygen Testing

2.3, Subtask III – Pretest Coordination (cont.)

The test matrix, as shown in Table 3 was presented and discussed along with the general test schematic, Figure 4. Several exchanges of information were made during the following months. These are documented in the following Appendices:

Table 3

OTV Oxygen Turbopump Test Matrix

Test Series	Objective	Shaft Speed (rpm)	Turb. Inlet Temp, Gas (°F)	Pump Discharge Orifice	Operating Time (Minutes)	No of Start/Stop Cycles	Bearing Lift-Off System
1	Checkout	0-75,000++	Ambient N_2	Nom Q/N	As Req'd	As Req'd	On
2	Performance Verification	0-75,000++	Ambient O_2	Nom Q/N	2	1	On
				90% Q/N	2	1	On
				80% Q/N	2	1	On
				120% Q/N	2	1	On
				60% Q/N	2	1	On
				40% Q/N	2	1	On
3	Heated O_2 Drive	0-75,000++	400°F O_2	Nom Q/N	9	3	On
4	Durability Testing	0-75,000*	400°F O_2	Nom/Q/N	Max+	100 (Goal)	Off
5	Thermal Margin (Optional)	0-75,000	425°F O_2**	Nom Q/N	1	1	On
			450°F O_2		1	1	On
			475°F O_2		1	1	On
			500°F O_2		1	1	On

* Speed may be reduced to increase number of start/stop cycles for each loading of the run tank
** Temperatures to be held within +25, -0 °F.
\+ Number of start/stop cycles is assumed more important than total operating time. Operating time begins at start rotation and ends at stop rotation. A teardown inspection will be made after any test where there is some indication that the equipment may be damaged.
++ Maximum shaft speed may be less due to facility limitations.

Appendix B: Test Plan Submittal – This plan was officially submitted 31 August 1989. It includes the objectives, test matrix, instrumentation and data processing requirements.

Appendix C: Updates Schedule – A transmittal was sent to NASA LeRC to update the schedule due to WSTF slips.

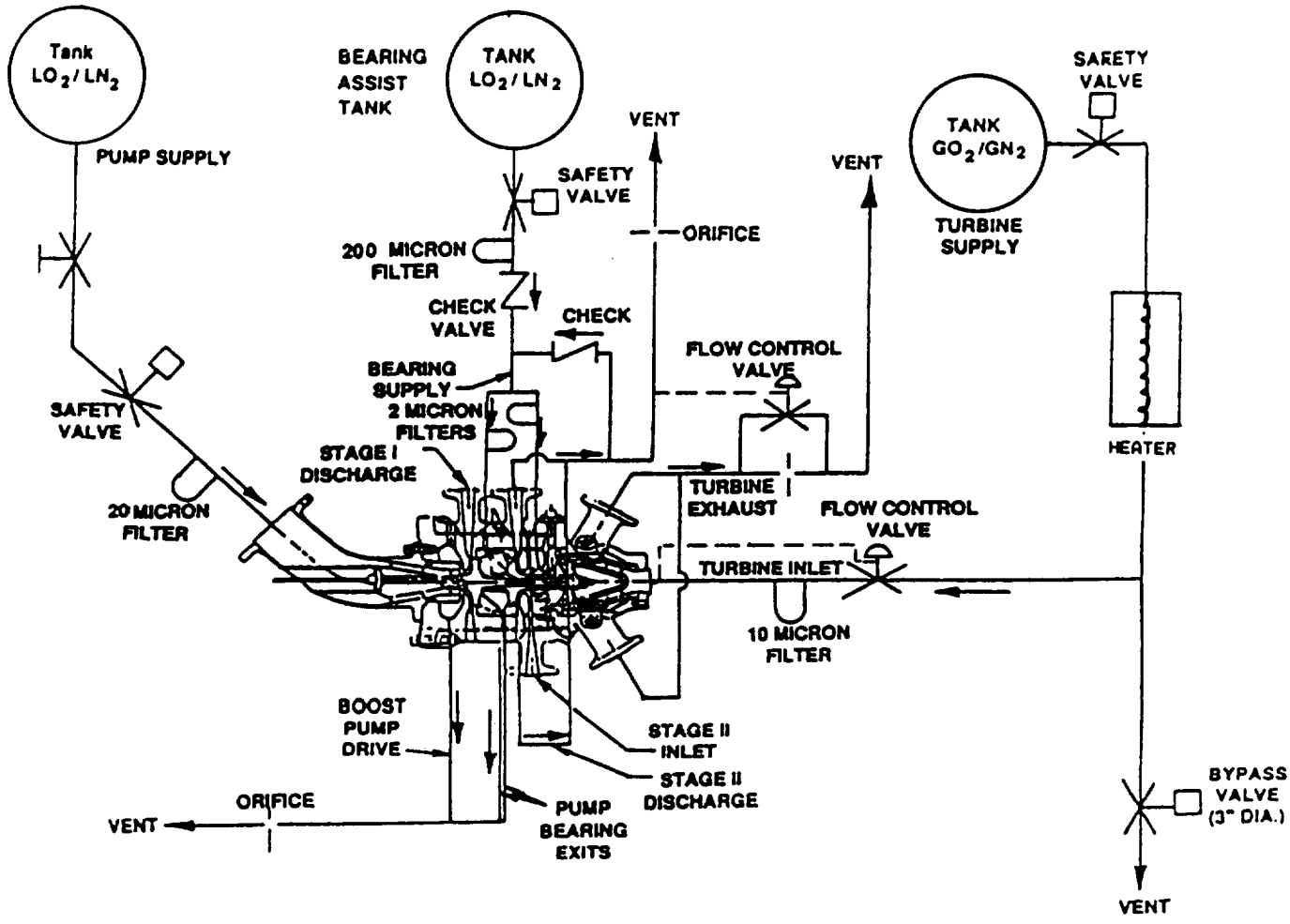

Figure 4. Test Schematic Series F and G

2.3, Subtask III – Pretest Coordination (cont.)

Appendix D: Further transmittals of requested data to WSTF were made 22 December 1989. This included photos of test set up and equipment and videos of oscilloscope data of shaft motion.

Also accomplished in pretest coordination were many "action item" resolutions. There are as follows:

- NASA LeRC shipped a 300 gallon LN_2 jacketed oxygen tank to WSTF for Ox TPA bearing pressurization. It was received on 29 November, 1989. This eliminates the need for any new tanks. Cleaning to LOX standards is underway.

- The mockup valves are through design and test. The operational valve drawings were sent out to fabrication on 19 January with fabrication started the week of 22 January 1990.

- Test stand fabrication started the week of 22 January 1990.

- The WSTF test area schematic was put in final form on 19 January 1990. A copy was FAXed to Aerojet and NASA LeRC with full size drawings sent by Federal Express. The schematic was reviewed by Aerojet test and TPA group engineers. Appendix E contains the results of that review including comments for WSTF to place valve characteristics on the drawing.

- The search for a common high density recording/storage medium for the data collected during testing has identified a TK50 VMS compatible tape system as the easiest for WSTF to record on and Aerojet to process. Data will be recorded on the tape, sent to Aerojet by overnight mail, processed on arrival, and evaluated by the Aerojet TPA group for information feedback to the WSTF test team no later than 3 days after the test. Quick look data will be used for real time post test decision making at WSTF. The capability to resolve anomalous situations within 3 days of the test should prevent excessive posttest downtime.

- Agreed that no filter would be used for the hot GOX supply to the TPA turbine as WSTF considers a filter a fire hazard and their hot GOX system is clean.

- A WSTF team consisting of David Reeves, Allen Porter, Morgan Phillips, and David Baker arrived at Aerojet on 19 September 1989 for a full day visit. A

2.3, Subtask III – Pretest Coordination (cont.)

variety of hardware was examined and selections made for use by WSTF in their test area buildup. Aerojet shipped these items via Federal Express on 20 December 1989. Aerojet provided a list of the parts to be sent prior to the shipment.

- Aerojet shipped the TPA housing and one proximeter probe at the same time (WSTF request) as the other test hardware.

- WSTF was asked to save the TPA shipping container for the return of the TPA housing for the first pump buildup at Aerojet.

- In lieu of a turbine inlet filter it was agreed that WSTF would sample the hot GOX flow to conduct a particle count and purity analysis prior to each test.

- NASA LeRC will evaluate the effect of temperature errors in the computation of TPA efficiency.

- Completion of instrumented crossover tube fabrication is delayed until mid-February. Problems with the fabrication prompted a visit by the Aerojet Project Engineer and Producibility Engineer to Hydraulic Tube Bending, Hayward, CA, on 22 January 1990. Flanges will need to be cut off, remachined, and rewelded onto the monel tube to correct dimensional errors. All parts should be salvageable, but material is available for new flanges if needed.

- Test results from the WSTF 250 area flow checks were received at Aerojet on 13 November 1989. A flowrate of 5 lbm/second of 400°F oxygen was sustained for over 300 seconds at expected system pressure drops. The heating system seems to be performing adequately for the test requirements.

- Recording the Bentley/Kaman proximeter probe data is possible on both computer tape or FM tape (analog). LeRC suggests both mediums be used. Final decision has to be coordinated prior to start of test.

- The proposed ramp up rate of 4000 rpm/sec is hard to achieve. WSTF may need a higher rate. Actual Aerojet rates were as high as 20,000 rpm/second.

2.3, Subtask III – Pretest Coordination (cont.)

- MicroMotion flowmeters will be used by WSTF to measure oxygen inlet flow and flow at other points in the system. Aerojet concurs with this flowmeter choice.

- The Kaman probes arrived at Aerojet in early January 1990

- Bentley probes due in on 28 February 1990.

- All TPA parts storage at WSTF is in a controlled access area.

Recent discussions with Bentley and Kaman regarding procurement of speed probes for use in Series "F" testing have yielded the following results:

- The Bentley Nevada Co. has advised us that they may withdraw their bid if their probe, as initially fabricated and tested, does not meet specifications. NOTE: Bentley made the probes used on the Series A through E testing to essentially the same specification. They contend the poor performance record of these probes is a result of trying to meet requirements beyond their technical capability. However, they have supplied probes which are performing satisfactorily on the dual spool hydrogen turbopump currently undergoing testing on the Air Force Low Thrust Cryogenic Engine Technology Program (XLR-134).

- A complication with calibrating the Kaman probes has been identified. If a K-500 monel target is used (the material of the TPA shaft) there will be a calibration shift as the TPA is cooled below -200°F, the Curie point for K-500. Probe seeing temperatures above -200°F should be set up with a plug-in circuit element suitable for room temperature calibration. This would be the case near the turbine section during hot GOX testing. Probes at LOX temperatures would use a different plug-in circuit element and would be calibrated at LN_2 temperature. This situation is being evaluated to assure the best way of using the Kaman probes. Kaman will supply extra plug-in circuit elements so that we can convert any probe signal conditioning unit for either cryogenic or room temperature calibration.

2.4 SUBTASK IV AND V

The program was put on hold in February 1990. No further funding was received and therefore no program was conducted beyond the pretest coordination shown in Section 2.3. As a result, Subtask IV, Series F Testing, and Subtask V, Data Reduction and Analysis were not accomplished.

3.0 CONCLUSION

3.1 ACCOMPLISHMENTS

The OTV program has been very impressive. Running an all-oxygen TPA is a challenge both as a design and as a test article. Up through Task E the demonstration of this TPA was very successful. Key items demonstrated were:

- Unassisted Rub Starts in liquid oxygen
- Pump and turbine performance
- Mechanical arrangement at high turbine pressures
- Ambient oxygen gas drive
- Demonstration of throttling

This task is basically the last task of a series beginning with the definition of the dual expander cycle. This somewhat new cycle dictated an all-oxygen TPA which solves two basic problems with cycles such as the single expander cycle: Higher power demands on the hydrogen TPA and an interpropellant seal in the Ox TPA. This led to the basic purpose of this task – Test an oxygen driven oxygen turbopump.

During this task several accomplishments were made in attaining the goal of the "hot" oxygen testing. These include the following:

- Submissions of Plans; both Task Order and Test Plans
- Refurbishment of TPA hardware
- Initial work on proximity probe coordination between APD, WSTF, and Kaman Corp. Addressed many of the practical issues in the receiving and recording of the probe signals.
- Developing and coordinating Test Schematics
- Initiating test stand build up, including;
  - TPA sent to WSTF for mock-up
  - Valves for mock-up through design and test
- Completion of TPA turbine nozzle cold flow and analysis

This program along with the effort on oxygen compatible materials proves this to be an achievable goal. It has been shown to be successful with ambient oxygen and needs to be demonstrated in warm oxygen (400°F). This will be done when the program resumes.

3.2 FUTURE PLANS

The turbopump is ready for further testing pumping liquid oxygen with the turbine driven by warm oxygen gas (400°F GOX). Initiation of this testing is anticipated in the early 1990's to support this promising engine cycle.

4.0 REFERENCES

1. Buckmann, P.S., Hayden, W.R., Lorenc, S.A., Sabiers, R.L., Shimp, N.R., "Orbital Transfer Vehicle, Oxygen Turbopump Technology, Design Fabrication and Series A and B Testing, Final Report, Volume I," Aerojet Report No. 2459-54-2, Contract NAS 3-23772, NASA CR 185175, August 1989.

2. R.J. Brannam, P.S. Buckmann, B.H. Chen, S.J. Church, and R.L. Urke, "Orbital Transfer Vehicle Oxygen Turbopump Technology, Nitrogen and Ambient Oxygen Testing, Final Report, Volume II," Aerojet Report No. 2459-56-1, Contract NAS 3-23772, NASA CR 185262, December 1990.

APPENDIX A

Task Order B.8 Work Plan

GENCORP AEROJET

cc:
DA Blagg, RJ Brannam,
WR Hayden, S Otis,
SJ Reed (2), D Vronay,
File: NASA 3-23772, RF

Aerojet TechSystems
P O Box 13222
Sacramento CA 95813-6000
916-355-1000

29 August 1989

9001:DM2517
SJR:ple

National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. G. Paul Richter, MS 500-220

Subject: Contract NAS 3-23772, Orbit Transfer Rocket Engine Technology Program

Reference: (a) NASA Task Order NAS 3-23772-B.8
Work Plan - Oxygen Turbopump Assembly Test Program - Test Sequence "F" Hot Oxygen Testing

Gentlemen:

In accordance with Reference (a), three (3) copies of Enclosure (1) are submitted.

Very truly yours,

Debra A. Blagg
Contract Manager

Enclosure:

(1) NASA Task Order NAS 3-23772-B.8
Work Plan - Oxygen Turbopump Assembly Test Program - Test Sequence "F" Hot Oxygen Testing

SR 2517

ORBITAL TRANSFER VEHICLE
PROPULSION TECHNOLOGY

OXYGEN TURBOPUMP ASSEMBLY
TEST PROGRAM
TEST SEQUENCE 'F'
HOT OXYGEN TESTING

TASK ORDER B.8

WORK PLAN

Revised 24 August 1989

AEROJET TECHSYSTEMS COMPANY

R. J. Brannam
Task Leader
OTV OX Turbopump

W. R. Hayden
Project Engineer
OTV

D. F. Vronay
Program Manager
OTV

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I. INTRODUCTION

The NASA Lewis Research Center has sponsored high performance LOX/LH_2 space engine technology for many years. Since April 1983 this work has been specifically directed at establishing the technical base for the Orbit Transfer Vehicle engine. This engine is conceived as state-of-the-art in performance and operational flexibility. The performance emphasis led to the selection of an expander cycle as a means of maximizing performance without the perceived shortcomings of the staged combustion cycle. Aerojet TechSystems (ATS) evaluated the conventional expander cycle using hydrogen as a working fluid. This led to development of an advanced expander cycle called the dual expander cycle. The cycle schematic is shown in Figure 1 in the 7.5K lbf thrust version that has been carried through the preliminary design phase of development.

At the heart of the dual expander cycle is an all oxygen turbopump. The hydrogen expander cycle has an oxygen turbopump driven by supplying hot hydrogen gas to the turbine after first driving the hydrogen TPA. The oxygen pump can also be driven by a gear train deriving power from the same hydrogen gas that drives the hydrogen TPA. In either case the power to drive the oxygen pump is taken from the hydrogen gas enthalpy change and limits the efficiency of the system. The advanced all oxygen TPA uses a 400°F oxygen stream that derives its power from energy gained in the oxygen cooled nozzle extension and residual heat from the turbine gas flowing to the injector. A substantial additional benefit is to have both turbopumps free from interpropellant seals and the need for a heavy helium purge gas system on the vehicle.

The development of an all oxygen TPA required the identification and use of TPA materials compatible with 400°F high pressure oxygen. This was considered a serious enough requirement that NASA LeRC sponsored an Oxygen/Materials Compatibility Program with ATS and WSTF that did fundamental research and testing on this compatibility problem. The results encouraged a continuation into fabrication and testing. This critical technology demonstration was divided into three test programs with their own schedule and test requirements. They were:

Series A & B Hydrostatic bearing demonstration in liquid nitrogen. (completed)

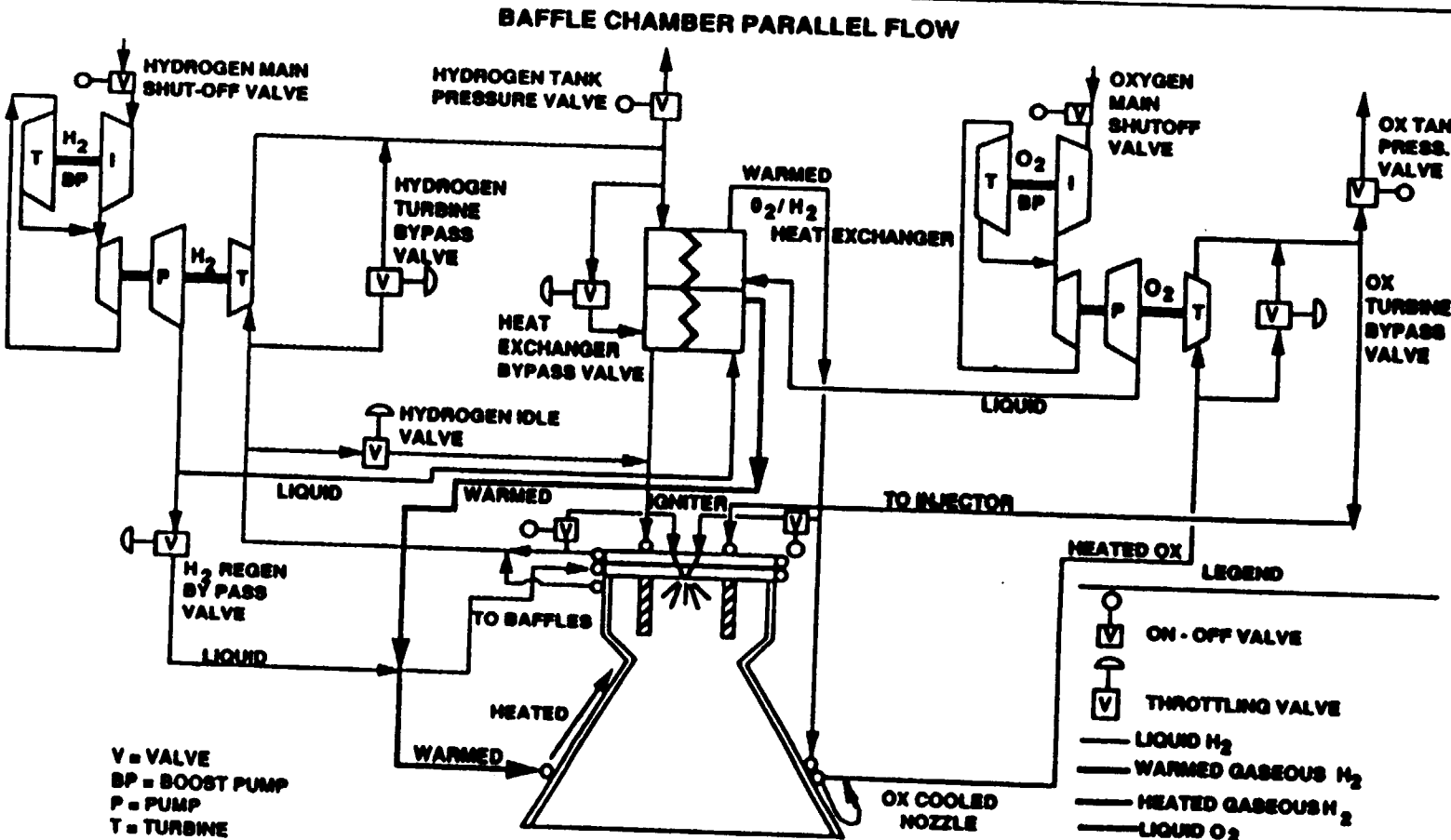
Series C, D, & E Oxygen TPA operation in liquid nitrogen and liquid oxygen with ambient temperature oxygen turbine drive. (completed)

Series F Oxygen TPA Operation with liquid oxygen and 400°F oxygen turbine drive. (An optional Series G, not part of this Work Plan would extend the testing to 500°F oxygen turbine drive to demonstrate thermal margin.)

The Series A and B testing was completed in May of 1987 with a 72,000 RPM test of the hydrostatic bearing. The completion of test article fabrication and test facility build-up occupied the remainder of 1987 and all of 1988. Series C, D and E testing was completed on 21 March 1989. The Series F testing is expected to be completed prior to the end of 1989. Earlier work plans covered this Series A through E testing. This Series F work plan is a stand alone document in that it is independent of the earlier testing programs.

AEROJET TechSystems COMPANY

OTV Engine
Dual Expander Cycle



3.4.0.14

II. OBJECTIVES

The primary objective of Series F testing is to demonstrate the safe and reliable operation of the LOX turbopump driven by 400°F gaseous oxygen in the turbine. Secondary objectives are to:

1. Validate the material selection and compatibility with oxygen by demonstrating start-up and high speed operation of the turbopump without a fire or other oxygen related damage.

2. Demonstrate unassisted bearing starts, which means only tank head pressure (60 psia) is applied to the hydrostatic bearings during startup until the pump discharge pressure overrides the external pressure supply.

3. Demonstrated durability by accumulating as much operating time and start/stop cycles as possible. The goal for service free life is 4.0 hours and 100 starts.

4. Collect additional performance data as specified in the accompanying approved Series F Test Plan.

(The optional Series G testing has the objective of demonstrating thermal margin by extending the testing to 500°F oxygen turbine drive).

III. REQUIREMENTS

The basic requirement is to operate this oxygen TPA as a liquid oxygen pump with a 400°F gaseous oxygen turbine drive. If facility capabilities permit, the TPA will demonstrate 75,000 RPM operation with 400°F drive gas. The temperature is the critical variable, and must be attained for a successful test although a lower operating speed is acceptable. Facility limitations on flowrate versus oxygen temperature will set a limit on attainable operating speed. The 400°F temperature is a nominal operating point. Lower temperature operation is expected during system checkout.

Detailed test requirements are given in the Series F Test Plan. This plan defines facility schematic and operating sequence, instrumentation, data and photographic (video and stills) requirements. When approved, the Test Plan will be considered part of this Work Plan and may be updated separately.

The possibility of fire damage to metal parts in hot oxygen service is always a concern. In the event of fire damage the hardware will be examined, photographed, and metallurgically evaluated to determine a failure cause if possible. This evaluation shall be included in the final report along with design recommendations to preclude a recurrence.

Successful operation and test completion shall be followed by a teardown and in-depth evaluation of the hardware to assess the compatibility of the various metal parts with 400°F oxygen. These observations shall be documented and included in the final report with emphasis on the demonstrated suitability of the various metals for hot oxygen service.

IV. PROGRAM DESCRIPTION

The Series F Test Program is currently planned to span approximately 44 weeks with completion within calendar year 1990. The activity is divided into six subtasks:

A. Subtask 1 - Task Order Planning

When approved, this Work Plan completes the requirements for this subtask. Testing details are given in the test plan. Resource utilization and schedule are given in this work plan. The costs for ATS support of WSTF testing include turbopump refurbishment, engineering support, data reduction, task leadership, and final report preparation. The actual start test date will be adjusted as the facility WSTF schedule becomes better known.

B. Subtask 2 - TPA Refurbishment

Prior to shipping the turbopump to WSTF for installation, the following hardware modifications shall be made:

- Replate and remachine bore of turbine journal bearing
- Replate and remachine bore of pump journal bearing
- Replace "K" seals between MS fittings and turbopump housing
- Rework or replace speed/ proximity probes
- Replace several #2 screws
- Chase threads in turbopump housing
- Modify face seal groove in turbine nozzle
- Fabricate one (1) additional set of external crossovers to:

  1.) Remove mismatch between pipe and flange.
  2.) Add pressure and temperature sensing instrumentation at both ends of the crossovers.

The following testing will be performed prior to a Series F testing:

- Flow turbine nozzle to verify CdA

  - If area undersized, rework or replacement may be recommended, but will not be done as part of this effort.

Other recommendations may follow as information is assimilated.

C. Subtask 3 - Pretest Coordination

ATS shall provide consultation and support to WSTF sufficient to ensure a safe and efficient test setup. This includes telephone support, ATS site visitation by WSTF personnel, and any design, analysis or test support WSTF may require. This task will be conducted on a level-of-effort basis.

D. Subtask 4 - Series F Testing

Actual oxygen TPA testing shall be conducted per the Series F test plan approved by NASA LeRC.

E. Subtask 5 - Data Reduction and Analysis

NASA Whitesands shall record data as specified in the Series F Test Plan approved by NASA LeRC. NASA Whitesands shall also apply any calibrations and reduce the data to the engineering units specified in the approved Series F Test Plan. This reduced data shall be given to both Aerojet TechSystems and NASA LeRC in a format to be agreed upon prior to testing. Delivery will be within three weeks of completion of testing or sooner, if possible. Upon receipt of this data from WSTF, ATS shall perform further data reduction and analysis sufficient to characterize the key turbopump performance characteristics. The specific data and format to be presented in the final report shall be as mutually agreed to by NASA and ATS.

As part of this subtask ATS personnel shall perform a post test disassembly and inspection of the turbopump hardware. Results of the inspection shall be documented, including photographs, and included in the final report.

F. Subtask 6 - Reporting and Task Management

Data reduction requirements are contained in the test plan. The reduced data shall be the basis for program reviews and preparation of the final report. A draft final report shall be submitted to NASA LeRC within 30 days of completion of data reduction. Monthly technical progress reports shall be submitted until testing is completed. A summary oral report shall be presented at NASA LeRC following completion of the testing and prior to final CR report submission. The final report shall be a NASA Contractor's report and submitted 30 days after the receipt of NASA comments and CR number.

Fiscal status will be provided in three reports: Form 533M and 533P to be provided monthly and Form 533Q to be provided quarterly. ATS work order numbers shall be assigned to each subtask to facilitate accurate cost collection.

V. RESOURCE UTILIZATION PLAN

The planned expenditures for travel, ODC, and manhours are given in Table I.

The overall schedule for this plan is shown in Figure 2.

VI. REFERENCES

1. Test Plan for Orbit Transfer Vehicle (OTV) LOX Turbopump Testing, Test Series F and G, Hot Oxygen Drive, 1 August 1989, Series TechSystems, prepared for NASA LeRC.

2. Facility Plan - TBD, WSTF

AEROJET
TechSystems

Contract NAS3-23772,
Orbital Transfer Engine, Phase II

TABLE 1 : RESOURCE UTILITIZATION PLAN
TASK 8.8 : Test Series "F": Hot G/Ox TPA at WSTF

08:52 AM 24-Aug-89

		AFY:	JUNE 89	JULY 89	AUGUST 89	SEPT 89	OCTOBER 89	NOV 89	DEC 90	JAN 90	FEB 90	MARCH 90	APRIL 90	TOTAL
SubTasks:														
1: Task Planning & Site Survey WO# 2459-64	HRS		173	72	55									300
	LABOR $		$3,567	$1,485	$1,134									$6,186
2: TPA Refurb, Long-Lead Hdwe WO# 2459-65														
9938 Drafting LE					70	56								126 ✓
9934 TPA Engr, 9901 Engr Fisc					60	134	35							229 ✓
9342 Machine Shop LP HH					12	72								84
9342 Supervision LP SH					4	4								8
Other LR: 9510 Test, 9490 Qual					4	10	14							28 ✓
* Rev 1: Addition *														
* of new External *	SUBTASK TOTAL HRS				150	276	49							475
* Crossovers *	LABOR $				$2,983	$5,301	$1,010							$9,295
3: PreTest Co-Ordination WO# 2459-66	99XX Engr				12	52	16							80
	9510 Test Lab				12	52	16							80
	SUBTOT HRS				24	104	32							160
	LABOR $				$495	$2,144	$660							$3,299
4: Test Series F Testing WO# 2459-67	HRS					20	220	240						480
	LABOR $					$412	$4,536	$4,949						$9,898
5: Data Reduct/Analysis WO# 2459-68	HRS								280	240				520
	LABOR $								$5,972	$5,119				$11,092
6a: Task Leadership WO# 2459-69	HRS				36	60	48	48	60	36	33	20	20	361
	LABOR $				$1,080	$1,800	$1,440	$1,440	$1,800	$1,080	$990	$600	$600	$10,830
6b: Final Report WO# 2459-69	HRS									60	200	60	72	392
	LABOR $									$1,800	$5,620	$1,800	$1,932	$11,152
TASK SUMMARY	HRS		173	72	265	460	349	288	340	336	233	80	92	2,688
	LABOR $		$3,567	$1,485	$5,692	$9,658	$7,647	$6,389	$7,772	$7,999	$6,610	$2,400	$2,532	$61,751
	Matl					$5,405	$3,784							$9,189
	Travel		$5,175				$6,000	$4,000						$15,175
Based On 16 Aug 1989 Forward Pricing Rates except for identified Key Personnel Above LR Pool Rates (Task 6). Task 2 Includes LP & LE as noted.	Computer								$5,000	$3,000				$8,000
	Tech Pub									$300	$3,200		$1,500	$5,000
	MATL & ODC SUBTOTAL		$5,175			$5,405	$9,784	$4,000	$5,000	$3,300	$3,200		$1,500	$37,364
	OVERHEAD		$7,812	$3,251	$11,965	$22,154	$17,124	$13,991	$15,156	$15,598	$12,890	$4,680	$4,937	$129,560
	G&A		$2,933	$639	$2,384	$5,754	$5,986	$3,831	$3,886	$3,563	$3,056	$835	$1,235	$34,104
	MGT RESERVE												$3,099	$3,099
	COM		$268	$101	$385	$691	$569	$453	$477	$482	$401	$140	$155	$4,123
	COST/MONTH		$19,756	$5,476	$20,426	$43,662	$41,110	$28,665	$32,291	$30,943	$26,156	$8,055	$13,459	$270,000
	Cum Cost-EOM		$19,756	$25,232	$45,658	$89,320	$130,430	$159,095	$191,387	$222,330	$248,486	$256,542	$270,000	

Prepared by: Steven J. Otis

FOLDOUT FRAME 1 2

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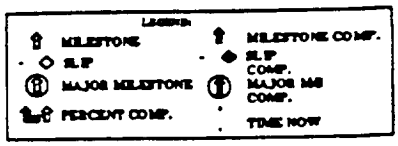
AEROJET
TechSystems



1990

TASK DESCRIPTION	WEEK #	1	2	3	4	34	35	36	37	38	39	40	41	42	43	44
	WEEK END	05/09	05/16	05/23	05/	01/26	02/02	02/09	02/16	02/23	03/02	03/09	03/16	03/23	03/30	04/06
1.0 TASK ORDER PLANNING																
1.1 SUBMIT WORK PLAN																
1.2 WSTF SITE SURVEY																
2.0 TPA REFURBISHMENT																
2.1 RESURFACE TURBINE JOURNAL BEARING																
2.2 RESURFACE PUMP JOURNAL BEARING																
2.3 REFURBISH DISTANCE DETECTORS																
2.4 REWORK TURBINE NOZZLE STATIC SEAL																
2.5 PURCHASE K SEALS																
2.6 PURCHASE V SEALS																
2.7 DESIGN, FAB DISTANCE DETECTOR SPACERS																
2.8 REMOVE TPA HOUSING GALLED FITTINGS																
2.9 REPLACE SCREWS																
2.10 DESIGN, FAB ASSY TOOL FOR #2 SCREW																
2.11 DETERMINE CdA OF TURBINE NOZZLE																
2.12 INSP NOZZLE THROAT																
2.13 DOCUMENTATION CHANGES																
2.14 CROSSOVER FABRICATION																
2.15 LOX CLEAN TPA																
2.16 TPA ASSEMBLY																
3.0 PRETEST COORDINATION																
4.0 OX TPA TESTING																
4.1 CER																
4.2 CONDUCT TESTING																
4.3 ONE (1) DISASSEMBLE AND REASSEMBLE																
4.4 WSTF DATA PROCESS																
5.0 DATA REDUCTION & ANALYSIS																
5.1 WSTF DATA RECEIVED AT ATC																
5.2 PUMP INSPECTION																
5.3 DATA ANALYSIS																
6.0 FINAL REPORT/TASK MANAGEMENT																
6.1 TASK LEADERSHIP																
6.2 DRAFT								SHIP TO NASA					RECEIVE DRAFT COMMENTS FM LERC			
6.3 FINAL															FINAL TO NASA 4/6	

FIGURE 2

APPENDIX B

Task Order B.8 Test Plan Test Series F and G

GENCORP AEROJET

cc:
DA Blagg, RJ Brannam,
WR Hayden, S Otis,
SJ Reed (2), D Vronay,
File: NASA 3-23772, RF

Aerojet TechSystems

P O Box 13222
Sacramento CA 95813-6000

916-355-1000

31 August 1989

9001:DM2530
SJR:ple

National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. G. Paul Richter, MS 500-220

Subject: Contract NAS 3-23772, Orbit Transfer Rocket Engine Technology Program

Reference: (a) NASA Task Order NAS 3-23772-B.8
Test Plan - Test Series "F" and "G"
Hot Oxygen Turbine Drive

Gentlemen:

In accordance with Reference (a), three (3) copies of Enclosure (1) are submitted.

Very truly yours,

Debra A. Blagg
Contract Manager

Enclosure:
(1) NASA Task Order NAS 3-23772-B.8
Test Plan - Test Series "F" & "G"
Hot Oxygen Turbine Drive

cc: White Sands Test Facility, New Mexico
Attn: Mr. Dave Baker, MS RF

SR 2517

TEST PLAN

FOR

ORBIT TRANSFER VEHICLE (OTV) LOX TURBOPUMP TESTING

TEST SERIES 'F' & 'G'

HOT OXYGEN TURBINE DRIVE

1 August 1989

Prepared for

NASA-Lewis Research Center

Contract Number NAS3-23772 -Task B.8

Prepared by

Aerojet TechSystems Company

R. J. Brannam
OTV TPA Task Leader

Date: 29 Aug 89

D. F. Vronay
Program Manager

Date: 8/30/89

W. R. Hayden
Project Engineer

Date: 29 Aug 89

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Appendix: Drawing Package
ATC Specification

1.0 Introduction and Scope

This document constitutes the test plan for evaluating the Orbital Transfer Vehicle (OTV) oxygen turbopump for that portion of the design verification testing using 400°F oxygen as the turbine drive gas. This is Series 'F' in a test program that began in 1987.

At this point in the program test series E_2 has been completed using ambient gaseous oxygen for the turbine drive fluid. The testing covered in this plan will extend the experience base to higher temperature (400°F) gaseous oxygen turbine drive gas. The Series 'F' tests will utilize the actual service fluid, 400°F gaseous oxygen, as the working fluid in the turbine and LOX in the pump circuits, providing a true simulation of operating conditions. The turbopump will accumulate additional operation time, demonstrate numerous start/stop cycles, and demonstrate additional hydrostatic bearing operation without prepressurization (lift-off). Tear down and examination of the TPA will complete the Series 'F' test series.

An optional extension to the testing, designated Series 'G', would add thermal margin tests. In Series 'G' the temperature of the turbine drive gas would be raised to 425°F, 450°F, 475°F, and 500°F in four separate tests. A teardown inspection would follow with particular attention to surfaces for any indication of thermal effects or degradation.

This test plan replaces the OTV LOX Turbopump Test Plan dated 20 March 1989. The testing is to be done at the NASA White Sands Test Facility. Details of instrumentation and plumbing are derived from the Aerojet testing, and may need to be changed to conform to the NASA-WSTF capability.

2.0 Objectives

The fundamental objective of the OTV Oxygen turbopump test program is to verify the design and operation of the high pressure LOX/GOX turbopump in a simulated rocket engine environment. The main technology and safety issue is the oxygen ignition potential from a metal-to-metal rub or particle impingement. The overall goal is to demonstrate the safe operation of an all oxygen TPA. The turbopump configuration uses hydrostatic bearings which provide a long-life, low-deflection, high-stiffness rotor/bearing system to control rub potential. Such bearings operate at close clearance for maximum efficiency. The intent of the test program is to demonstrate the viability of this design approach for high-speed LOX/GOX turbopumps, and develop a data base in this area.

Specific test objectives for the testing covered by this plan are outlined here with a brief discussion of each.

1. Demonstrate operation with 400 F gaseous oxygen driven turbine - Previous testing will have been performed with GN_2 and ambient-temperature gaseous oxygen. For this test, oxygen gas at a temperature of 400°F (nominal) will be used.

   The intent is to demonstrate safe operation free of ignition from material reaction, particle impingement, or rubbing friction at this higher temperature.

2. Demonstrate additional starts without bearing assisted liftoff. - This will validate the hydrostatic bearing durability in normal engine start conditions (400°F oxygen in the turbine). A total of 100 starts is desired.

3. Accumulate maximum operating time at rated speed - Four hours is desired to meet the design goal for the OTV oxygen turbopump. Facility limitations and test cost will determine the actual operating time and speed.

4. Demonstrate Thermal Margin (Optional) - Conduct four tests with turbine drive gas at 425, 450, 475, and 500°F, respectively, to demonstrate thermal margin. Conduct a thorough teardown inspection for evidence of any thermal degradation or damage after performing the 500°F test.

3.0 Description of Test Unit

The OTV LOX turbopump consists of a two-stage centrifugal pump driven by a single-stage axial turbine on a common shaft. The first pump stage incorporates an inducer section for improved suction performance. The interstage pump flow is routed external to the main housing through two ducts connecting first-stage discharge to second-stage entry. A flight type turbopump would use internal crossover passages for reduced weight. The shaft system is supported by two journal-type hydrostatic bearings supplied with high pressure LOX from the second stage pump discharge. Both bearings articulate on spherical seats, providing a measure of compensation for possible misalignment and/or transient thermal distortion. Design speed is 75,000 rpm. The hydrostatic bearings, utilizing the high pressure pump discharge fluid, provide a very stiff support for the rotor system. This facilitates sub-critical operation with ample margin, and very small shaft displacements at all speeds. The result is high efficiency in the turbomachinery by virtue of the tight running clearances which can be accommodated.

Provision is made for future addition of a hydraulic boost pump, with an internal extraction point at the inducer discharge and a flanged port in the outer housing. Although the boost pump is not incorporated for this test, the flow for boost pump drive will be tapped off and measured.

The test configuration of this turbopump is defined in ATC drawing No. 1197585-9 and sub-tier drawings. The test unit incorporates special instrumentation which is outlined in detail in Section 8.0. The instrumentation provided with the turbopump assembly consists of a sensor for housing temperature, (item number 10 in Table 8.2-1) and shaft displacement (item numbers 16, 17, and 18 in Table 8.2-1). Mounting pads for accelerometers will be available, but the accelerometers will be facility furnished. All other instrumentation for fluid flows, pressures and temperatures shall be provided by the testing facility.

4.0 Drawings and Specifications

The following drawings and specifications are applicable in the performance of the test program to the extent indicated in this test plan.

Drawings

1197585	OTV LOX Turbopump
TBD*	Test Stand Installation

Specifications

ATC-STD-4940C	Cleanliness Requirements

*The test stand installation drawing shall be prepared by the WSTF test facility engineer and submitted to NASA LeRC and Aerojet for approval.

5.0 Test Approach

5.1 Description of Test Approach

The overall approach to development testing of the OTV LOX turbopump involved a progression from a pure bearing test with a separate LN_2 supply to the bearings and an external drive turbine, through testing as a turbopump configuration with ambient GOX turbine drive and LOX in the pump circuits, to culminate in the test covered by this plan where the turbine is driven by heated GOX and durability is demonstrated by both operating time and the number of start/stop cycles.

The test series below differ in the use of hydrostatic bearing assist pressurization or in an unassisted start. In Sequence 1 through 3 the hydrostatic bearings shall be pressurized from an external source prior to the start of rotation to assure the presence of liquid in the bearings. The turbine drive gas shall be oxygen. A check valve shall be provided in the lift-off pressure line such that it shuts off when pump discharge pressure reaches a predetermined value and takes over the job of pressurizing the hydrostatic bearings. In Sequence 4 this external pressure source shall be set to the same value as pump inlet pressure so that bearing lift-off occurs as a result of pump discharge pressure alone as it increases with pump speed. This will demonstrate the capability of the hydrostatic bearings to start damage-free and ignition-free in LOX without the need for a lift-off system. In Sequence 5 (optional) bearing assist pressurization is again used.

The approach to the Series 'F' test program builds on the experience gained in prior phases with only those tests being repeated that confirm facility operation and equipment readiness. The basic steps in the test program are outlined below:

1. Checkout: A facility operation and valve calibration series shall be run using GN_2 turbine drive and LN_2 in the pump to assure maximum safety to the TPA while all ramp rates and kill settings are determined. The pump discharge orifice for nominal Q/N (pump discharge flow to speed ratio) shall be installed. Once the valves and kill parameters are properly set to allow full speed (75,000 rpm) operation, a calibration run shall be made to full speed with pauses at 25,000, 35,000, 45,000, 55,000, 65,000 and 75,000 rpm to record full data at each speed. Observe accelerometer and shaft displacement detector signals over this speed range for signs of excessive shaft motion in both the axial and radial axes. If no annomalies are observed the next sequence shall be started.

2. Performance Verification: The TPA will be operated over the entire speed range at six Q/N values for performance verification. The turbine drive gas shall be ambient temperature oxygen. Data shall be recorded at 30,000, 45,000, 60,000 and 75,000 rpm for each Q/N value. This is necessary to verify that TPA performance after the teardown inspection and any necessary rework following Test Series 'E' testing has not changed.

3. Heated Oxygen Drive: This test will introduce heated oxygen into the turbine for the first time. The turbine inlet temperature will be 400°F (nominal) for this test and the pump discharge orifice for nominal Q/N will be installed. Accelerate through the speed range, pausing (only as required to obtain "steady" data) at speed increments of 15,000 rpm to record all parameters until the design speed of 75,000 rpm (or facility limit) is attained. Monitor accelerometer and distance detector signals closely during the test using high "g" accelerometer values and overspeed values as shutdown signals.

4. Durability Testing

The condition for this portion of the test program will be 75,000 rpm (or facility limit) shaft speed with the pump discharge orifice for nominal Q/N installed. The turbine drive gas will be heated oxygen. At the end of this duration testing the total number of start/stop cycles shall be 100. The operating time on each run shall be at the discretion of the Test Laboratory and the durations of the runs may vary in order to attain the maximum total time and total number of cycles with available tank capacities. Time accumulated at 75,000 rpm in Sequence 1 through 3 above shall be counted when computing total running time. Start/stop cycles accumulated in Sequence 1 through 3 shall not be counted towards the goal of 100.

Following the test sequence 4 (no bearing assist pressure) the TPA shall be disassembled and thoroughly inspected. Photographs and/or measurements shall be made to document any wear or surface damage. AT that time a decision shall be made jointly by both NASA and Aerojet whether the TPA can or cannot be rebuilt "as is" for additional testing. If the TPA can be used without refurbishment it will be reassembled for use in the thermal margin test series (optional).

5. Thermal Margin Testing (Optional): The rebuilt TPA will be tested at increasing oxygen temperatures to the turbine until a run is made at 500°F. Four tests of one minute duration each are planned at 425, 450, 475, and 500°F (+25,-0°F). Following the last test the turbopump shall be disassembled for a thorough inspection. Measurements and/or photographs shall be taken for comparison with the teardown inspection in the previous series.

5.2 Test Matrix

The test matrix for the program is shown in Table 5.2-1.

TABLE 5.2-1
OTV OXYGEN TURBOPUMP TEST MATRIX

Test Series	Objective	Shaft Speed (rpm)	Turb. Inlet Temp, Gas (°F)	Pump Disch. Orif.	Operating Time (Minutes)	No. of Start/Stop Cycles	Bearing Lift-Off System
1	Checkout	0-75,000++	Ambient N_2	Nom Q/N	As req'd	As req'd	On
2	Performance Verification	0-75,000++	Ambient O_2	Nom Q/N	2	1	On
				90% Q/N	2	1	On
				80% Q/N	2	1	On
				120% Q/N	2	1	On
				60% Q/N	2	1	On
				40% Q/N	2	1	On
3	Heated O_2 Drive	0-75,000++	400°F O_2	Nom Q/N	9	3	On
4	Durability Testing	0-75,000*	400°F O_2	Nom Q/N	Max+	100 (Goal)	Off
5	Thermal Margin (Optional)	0-75,000	425°F O_2**	Nom Q/N	1	1	On
			450°F O_2		1	1	On
			475°F O_2		1	1	On
			500°F O_2		1	1	On

*Speed may be reduced to increase number of start/stop cycles for each loading of the run tank

**Temperatures to be held within +25, -0 °F.

+Number of start/stop cycles is assumed more important than total operating time. Operating time begins at start rotation and ends at stop rotation. A teardown inspection will be made after any test where there is some indication that the equipment may be damaged.

++Maximum shaft speed may be less due to facility limitations.

6.0 Test Procedure

6.1 General Guidelines

The following guidelines are to be observed in the performance of the test program.

1. Insulation: Insulate LOX lines as necessary to achieve desired fluid conditions at the turbopump. Do not insulate the turbopump.

2. Cleanliness: The entire LOX flow circuit is to be cleaned and maintained to Aerojet TechSystems standard ATC-STD-4940C, Level 200A, or NASA equivalent.

3. Instrumentation: Check for proper functioning of all instrumentation prior to startup on each test day, and correct any problems found. For any subsequent test run where an instrumentation malfunction may occur, coordinate with the cognizant Project Engineer on whether to interrupt testing for repairs.

4. Data Recording: Start recording all parameters 10 seconds prior to start of LOX chilldown flow (see Section 6.2) and continue until shaft rotation ceases. A reduced data collection rate will be used prior to the start of shaft rotation.

5. Shaft Speed: Shutdown shall be initiated when shaft speeds exceed 6% of the specified values. Shutdown shall be initiated by shutting off the turbine drive gas supply. Overspeed shutdown requires response time sufficient limit shaft speed to less than 175,000 rpm maximum.

6. Pump Suction Pressure: Maintain at 50 psig, minimum, for all TPA rotational testing. A kill shall be set for 40 psig to prevent cavitation.

7. Hot Oxygen Temperature: The hot oxygen tests, Sequence 4, are to be run with gaseous oxygen at 400-425^{o}F. Tests run below this temperature bandwidth do not meet test requirements. Higher temperature operation is acceptable as a valid demonstration of TPA capability, but the increased reactivity of the oxygen jeopardizes the equipment. A thermal kill for the hot oxygen source shall be installed and set at 450^{o}F (Exception: Optional

thermal margin tests use a setting of 550°F) at the pump turbine inlet. Any exposure of the TPA to oxygen at 500 to 600°F shall be evaluated by the Project Engineering team for possible equipment damage. Any exposure of the TPA to oxygen over 600°F shall require a mandatory teardown inspection.

8. Bearing Assist Pressure: Bearing assist pressure, when required, shall be 500 psig ±50. Initial alignment pressure shall be 3000 psig. Alignment pressure shall be applied five times to align shaft after final assembly and prior to first shaft rotation.

9. Aerojet Participation: A member of the Aerojet Engineering staff shall be present for all test activity requiring TPA rotation. In addition, the Aerojet Program Manager, OTV Project Engineer, and members of Rotating Machinery Design shall participate in the formal Critical Experiment Review (CER) to be held at WSTF prior to test initiation.

6.2 Running Procedure

The following procedure is to be followed in the operation of the turbopump on test.

1. Purge: Pass ambient-temperature, dry nitrogen or helium (<50 ppm water) through the pump and turbine passages for 30 minutes minimum upon initial installation. This purge gas is to be filtered (10 micron nominal, 25 micron absolute) and supplied through the pump inlet and turbine inlet. This purge is to be flowed continuously thereafter anytime the flow passages are free of liquids. Test for moisture content limit ≤50 ppm on the effluent leaving the turbopump before each test.

2. Chilldown - Gas: Bleed boil-off gas from the oxygen supply tank into the pump inlet for preliminary chilling. This gas is to be passed through a 10 micron nominal (25 micron absolute) filter before entering the pump. Continue the process until the TPA housing exterior wall temperature (TTBHX) stabilizes or decreases at a low rate (e.g., 5°F per minute).

3. Chilldown - LOX: Pressurize pump suction to 50 psig minimum with liquid from the supply tank passed through a 10 micron nominal (25 micron absolute) filter. Chilldown is considered complete when pump discharge fluid temperature decreases to -250°F or lower and pump suction to -289°F. Note: Chilldown rate can be increased by flowing LOX through the bearing supply system, this may be done at pressures greater than available at the oxygen run tank. Project engineering coordination

is necessary in establishing a chilldown procedure that will expeditiously cool the TPA while minimizing rotation of the rotating assembly.

4. Bearing Assist: Bearing assist pressure shall be 500 ±50 psig.

5. Turbopump Rotation: Admit oxygen gas to the turbine inlet and increase turbine inlet pressure at a rate not to exceed 200 psi per second, until the desired shaft speed is attained. Do not exceed a turbine inlet pressure of 4900 psig at any time with a turbine discharge pressure to pump discharge pressure ratio of 0.5 and a turbine inlet to turbine exhaust pressure ratio of 2.0. In Test Sequence 3, the heat exchanger settings for delivering 400°F turbine inlet gas temperature will be determined. These settings will then be used for the duration test (Sequence 4).

6. Shutdown: Close the pump suction LOX valve after the turbine inlet valve is closed and rotation has ceased.

7. Shutdown Purge: If testing is to continue, purge with boil-off oxygen gas from the supply tank as described in Step 2 above. If there is to be a significant down time before further testing, return to the purge procedure of 6.2-1.

8. Automatic Kill Limits: A list of kill limits for critical parameters shall be supplied by AT to WSTF prior to testing.

9. Turbine Back-Pressure Control: Turbine back-pressure, measured as "PTDH", shall be controlled continuously using a flow control valve such that it is 40% to 60% of pump discharge pressure, i.e., PTDH = .6 PD2-1 to .4 PD2-1.

7.0 Facility Requirements

This section gives turbopump operating conditions pertinent to sizing and selection of facility components, and provides a tentative schematic for the essential elements of the flow circuit.

7.1 Turbopump Operating Conditions

The turbopump performance tabulation shown in Table 7.1-1 is provided to assist in determination of storage vessel capacities, line sizes, test run durations, pressure capabilities, and other parameters impacting the test facility design. The table gives nominal values for the variables shown.

7.2 Test Stand Flow Circuit

The Test Engineer shall prepare a schematic and a layout, using Figure 7.2-1 as a point of departure, showing the planned facility in greater detail and incorporating the changes needed. This detailed representation shall include the size and location of tanks, lines, valves, filters, and any other components in the circuit. Wherever possible existing components shall be used. The intent is to avoid any long lead time part(s) procurements.

The ATC Project Engineer shall be consulted during facility plan preparation. Concurrence between WSTF and ATC Project Engineer is desired prior to submission of the facility plan to ATC.

7.3 Safety

All items concerning hardware and/or personnel safety shall be resolved prior to facility plan approval.

A representative from the WSTF safety office shall review the facility plan and attend the review held prior to the first test.

Table 7.1-1

OTV LOX Pump Design Point

Pump	
Number of Stages	2
Weight Flow, lb/sec	5.5
Volume Flow Rate - Inducer, gpm	51.4
Volume Flow Rate - Impellers, gpm	34.1
Suction Pressure - psia	54.6
Discharge Pressure - psia	4654.6
Speed, rpm	75,000
Turbine	
Inlet Pressure, psia	4170
Exit Pressure, psia	2327
Weight Flow, lbm/sec	5.1
Inlet Temperature, ^{o}F	400

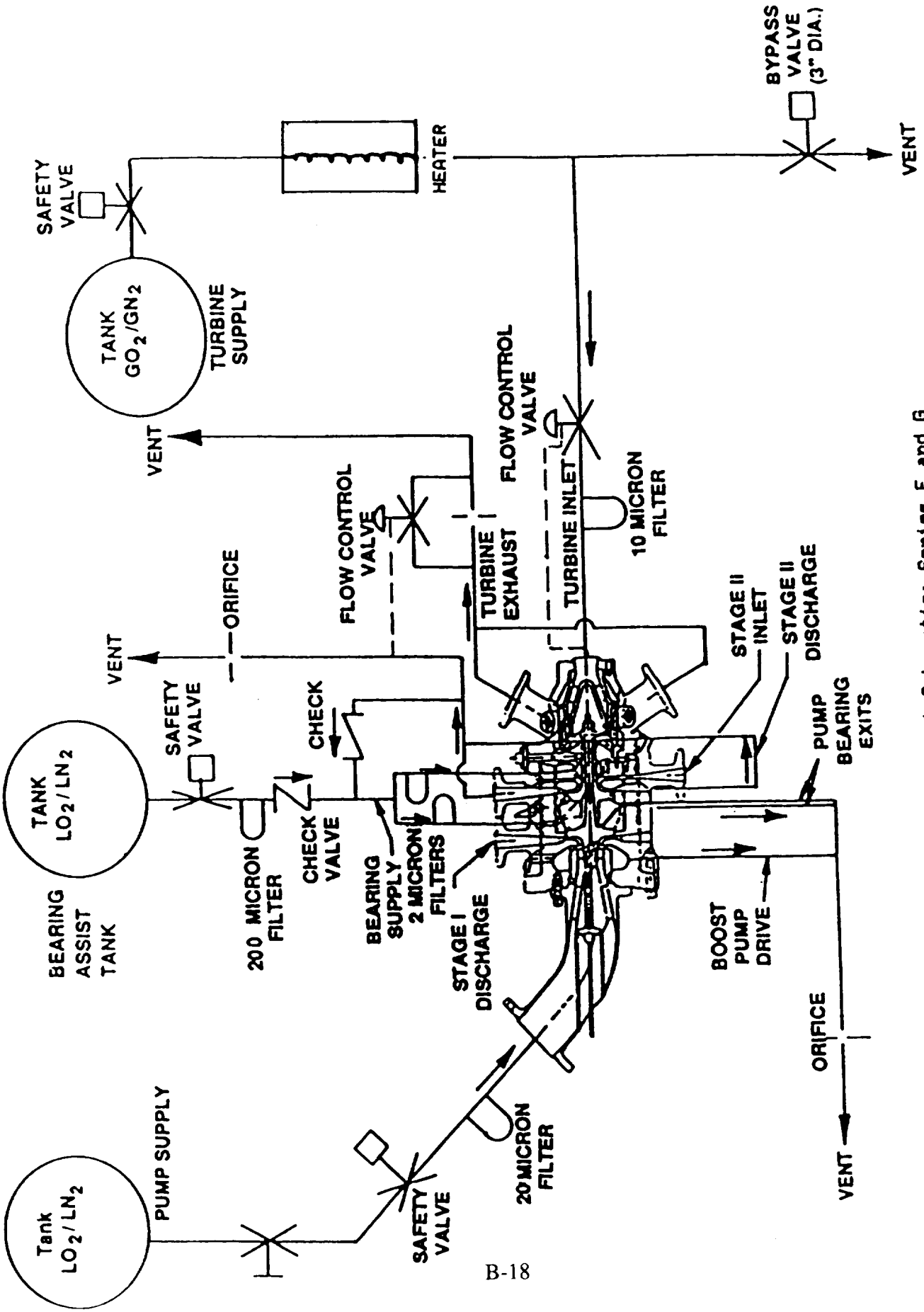


Figure 7.2-1. Test Schematic: Series F and G

8.0 Instrumentation

This section gives a definition of the instrumentation to be provided and data recorded for the LOX TPA test. The scheme for identification and location of instrument ports on the test unit is presented. The instrumentation list in Section 8.2 includes units, ranges, and type of instrument for all parameters to be recorded. The accompanying sketches relate the symbols in the instrumentation list to approximate locations on the test unit. Facility limitations may require this list to be revised.

8.1 Port Location Scheme

The instrumentation list gives nomenclature and locations for ports located on the test unit. The nomenclature refers to the symbol etched or tagged on the test unit. The approximate location of each port is designated by a distance and an angle as described in Figure 8.1-1.

8.2 Instrumentation List

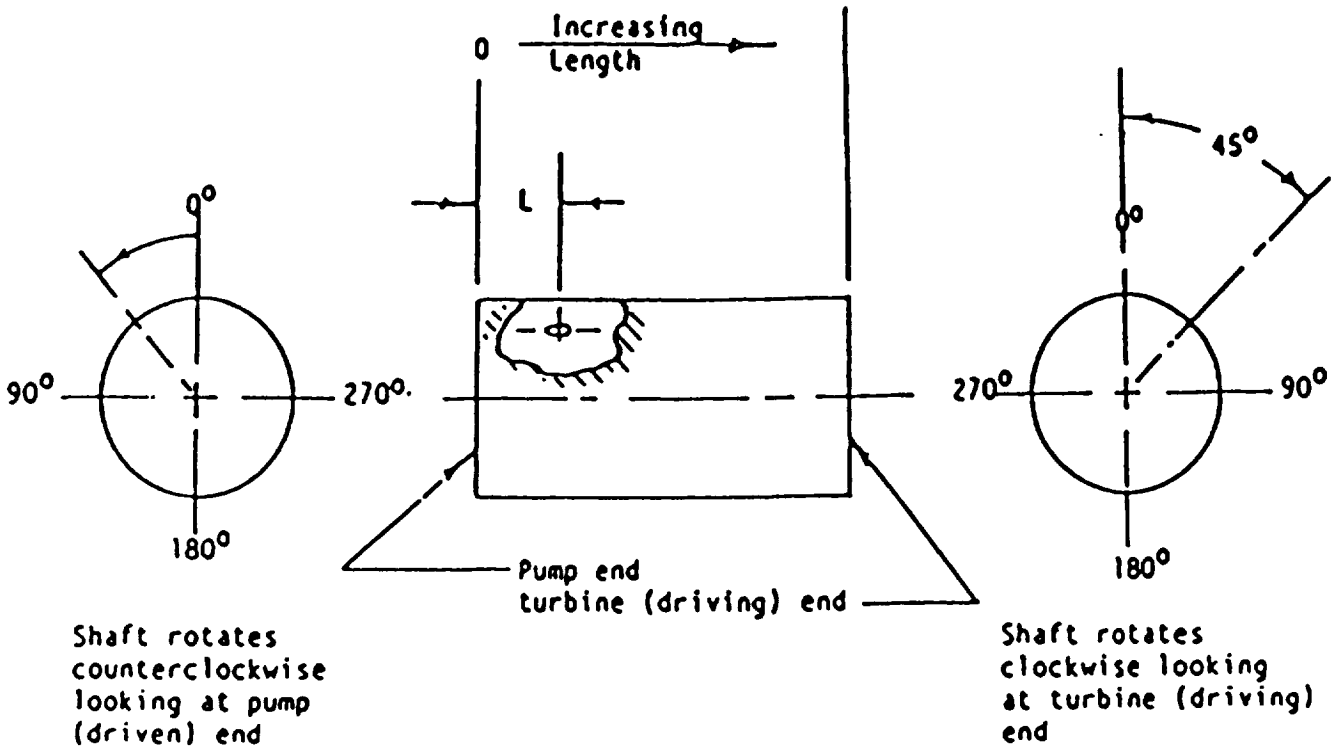
The instrumentation list is divided into the four functional types of wiring used to transmit the electrical output of the instruments: (1) a two-wire system, (2) a transducer system, (3) a high frequency system and (4) a specialized system.

The two-wire system is outlined in Table 8.2-1. The location of sensors is given on the flow diagram shown in Figure 8.2-1 for the installation at Aerojet. Two wire sensors are number coded, (n) .

The transducer system is outlined in Table 8.2-2. The location of thesensor is number coded, ◇n◇ , on the flow diagram in Figure 8.2-2.

The high frequency system is outlined in Table 8.2-3. The location of the sensor is number coded, [n] , on the flow diagram in Figure 8.2-3.

The specialized system is outlined in Table 8.2-4. the location of the special sensors are coded, [n] , on the flow diagram of Figure 8.2-4.



EXAMPLE:

Port location illustrated on cylinder outside diameter is noted as (L,45) for "L" distance from outside surface of the pump end in a plane 45 degrees from the vertical center line in a clockwise direction when looking from the turbine end. Location designator ignores radial distance.

Figure 8.1-1. Instrument Port Location Scheme

SYMBOL AND NO.	FUNCTION	TPA PORT NOMENCLATURE & LOCATION (INCH,DEGREES)	TEST LAB INSTRUMENT NOMENCLATURE	TYPE	UNITS & RANGE
1 *	TURBINE INLET TEMPERATURE		TTI	T/C	+0F TO +600F
2 *	TURBINE BEARING INLET FLUID TEMP	TBI	TBI	T/C	+100F TO -320F
3 *	PUMP BEARING FLOW RATE	PBI	FMPBI	TURBINE	0.5 GPM TO 15 GPM
4 *	PUMP DISCHARGE FLOW RATE	2SD1	FMPD1	TURBINE	2 GPM T0 30 GPM
5 *	PUMP DISCHARGE FLOW RATE	2SD2	FMPD2	TURBINE	2 GPM TO 30 GPM
6 *	TURBINE BEARING FLOW RATE	TBI	FMTBI	TURBINE	0.5 GPM TO 5 GPM
7	PUMP 1ST STAGE DISCHARGE TEMP	TSD1(3.03,70)	TPD1-1	T/C	+100F TO -320F
8	PUMP 1ST STAGE DISCHARGE TEMP	TSD2(3.03,250)	TPD1-2	T/C	+100F TO -320F
9 *	PUMP SUCTION FLOW RATE		FMSI	TURBINE	4 GPM TO 60 GPM
10	HOUSING EXTERIOR TEMP @ TURB BEARING	(3.79,0)	TTBHX	T/C	+100F TO -320F
11	TURBINE DISCHARGE HOUSING TEMP	TET (5.0,225)	TTDH	T/C	-100F TO +500F
12	PUMP BEARING EXIT TEMP	PBE1	TPBE	T/C	+100F TO -320F
13	BOOST PUMP DRIVE TURBINE FLUID TEMP		TBPD	T/C	+100F TO -320F
14	BOOST PUMP DRIVE TURBINE FLOW		FMBPD	TURBINE	0.5 GPM TO 10 GPM
15	PUMP BEARING INLET FLUID TEMP	PBI	TPBI	T/C	+100F TO -320F
16 *	PUMP SUCTION TEMP		TS	T/C	+100F TO -320F
17	2ND STAGE DISCHARGE TEMP		TPD2-1	T/C	+100F TO -320F
18	2ND STAGE DISCHARGE TEMP		TPD2-2	T/C	+100F TO -320F
19	PUMP BEARING EXIT FLOW RATE	PBE1 (2.54,120)	FMPBE	TURBINE	0.5 GPM TO 15 GPM
20	2ND STAGE INLET TEMP		TPI2-1	T/C	+100F TO -320F
21	2ND STAGE INLET TEMP		TPI2-2	T/C	+100F TO -320F

* CHANNEL TO BE DISPLAYED REAL TIME

TABLE 8.2-1. INSTRUMENTATION LIST - 2-WIRE CHANNELS

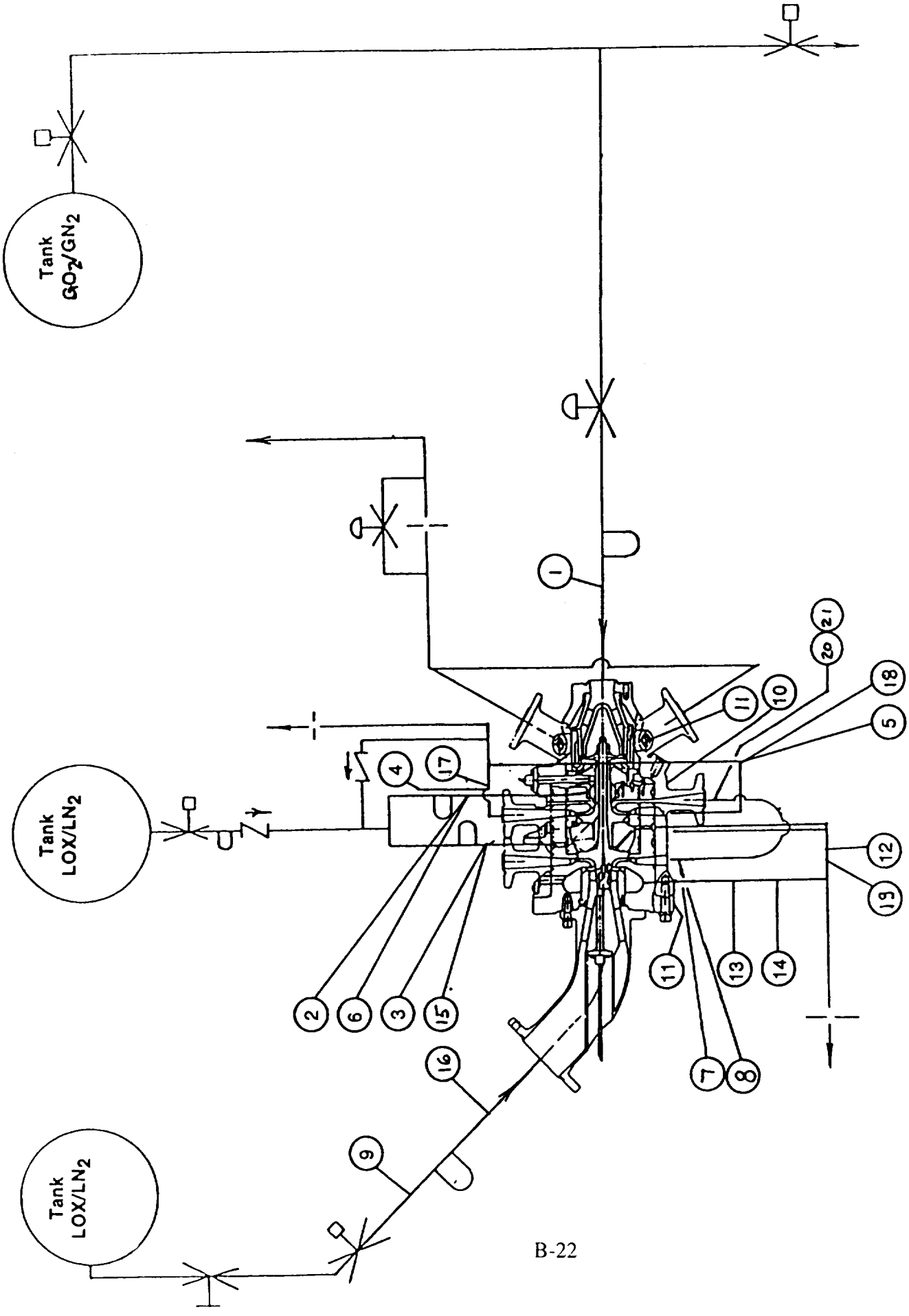


Figure 8.2-1. Instrumentation Locations — 2-Wire Channels

SYMBOL AND NO.	FUNCTION	TPA PORT NOMENCLATURE & LOCATION (INCH,DEGREES)	TEST LAB INSTRUMENT NOMENCLATURE	TYPE	UNITS & RANGE
1 *	PUMP BEARING INLET PRESSURE	PBI (2.06,330)	PPBI	TRANSDUCER	0 TO 5000 PSIA
2 *	TURBINE BEARING INLET PRESSURE	TBI (3.63,45)	PTBI	TRANSDUCER	0 TO 5000 PSIA
3	TURBINE EXHAUST PRESSURE	TD1 (5.81,90)	PTD1	TRANSDUCER	0 TO 2500 PSIA
4	TURBINE HOUSING EXHAUST PRESSURE	TEP (5.03,225)	PTDH	TRANSDUCER	0 TO 2500 PSIA
5	TURBINE EXHAUST PRESSURE	TD2 (5.81,270)	PTD2	TRANSDUCER	0 TO 2500 PSIA
6	PUMP PRESSURE, TIP	PP1 (0.0,330)	PPT	TRANSDUCER	0 TO 1000 PSIA
7	PUMP BEARING EXIT PRESSURE	PBE1 (2.54,120)	PBE	TRANSDUCER	0 TO 500 PSIA
8	PUMP PRESSURE, MID	PP2 (0.0,300)	PPM	TRANSDUCER	0 TO 2000 PSIA
9	TURBINE BEARING CAVITY PRESSURE	TBCP (4.64,45)	PTBC	TRANSDUCER	0 TO 2500 PSIA
10 *	SUCTION LINE PRESSURE		PS	TRANSDUCER	0 TO 150 PSIA
11 *	2ND STAGE DISCHARGE PRESSURE	2SD1 (3.03,70)	PD2-1	TRANSDUCER	0 TO 5000 PSIA
12	2ND STAGE DISCHARGE PRESSURE	2SD2 (3.03,250)	PD2-2	TRANSDUCER	0 TO 5000 PSIA
13	PUMP PERIPHERAL PRESSURE	PPP1 (0.0,0)	PPP1	TRANSDUCER	0 TO 2000 PSIA
14	PUMP PERIPHERAL PRESSURE	PPP2 (0.0,270)	PPP2	TRANSDUCER	0 TO 2000 PSIA
15	PUMP PERIPHERAL PRESSURE	PPP3 (0.0,180)	PPP3	TRANSDUCER	0 TO 2000 PSIA
16	PUMP PERIPHERAL PRESSURE	PPP4 (0.0,90)	PPP4	TRANSDUCER	0 TO 2000 PSIA
17	BOOST PUMP DRIVE LINE PRESSURE	BPP (0.86,15)	PBPD	TRANSDUCER	0 TO 500 PSIA
18 *	TURBINE INLET PRESSURE	(6.96,C'LINE)	PTI	TRANSDUCER	0 TO 5000 PSIA
19	BOOST PUMP SUPPLY, HOUSING PRESSURE	BPDP	PBPH	TRANSDUCER	0 TO 500 PSIA
20 *	1ST STAGE DISCHARGE PRESSURE		PPD1-1	TRANSDUCER	0 TO 2500 PSIA
21	1ST STAGE DISCHARGE PRESSURE		PPD1-2	TRANSDUCER	0 TO 2500 PSIA
22	2ND STAGE INLET PRESSURE		PPI2-1	TRANSDUCER	0 TO 2500 PSIA
23	2ND STAGE INLET PRESSURE		PPI2-2	TRANSDUCER	0 TO 2500 PSIA

* CHANNEL TO BE DISPLAYED REAL TIME

TABLE 8.2-2. INSTRUMENTATION LIST - TRANSDUCER CHANNELS

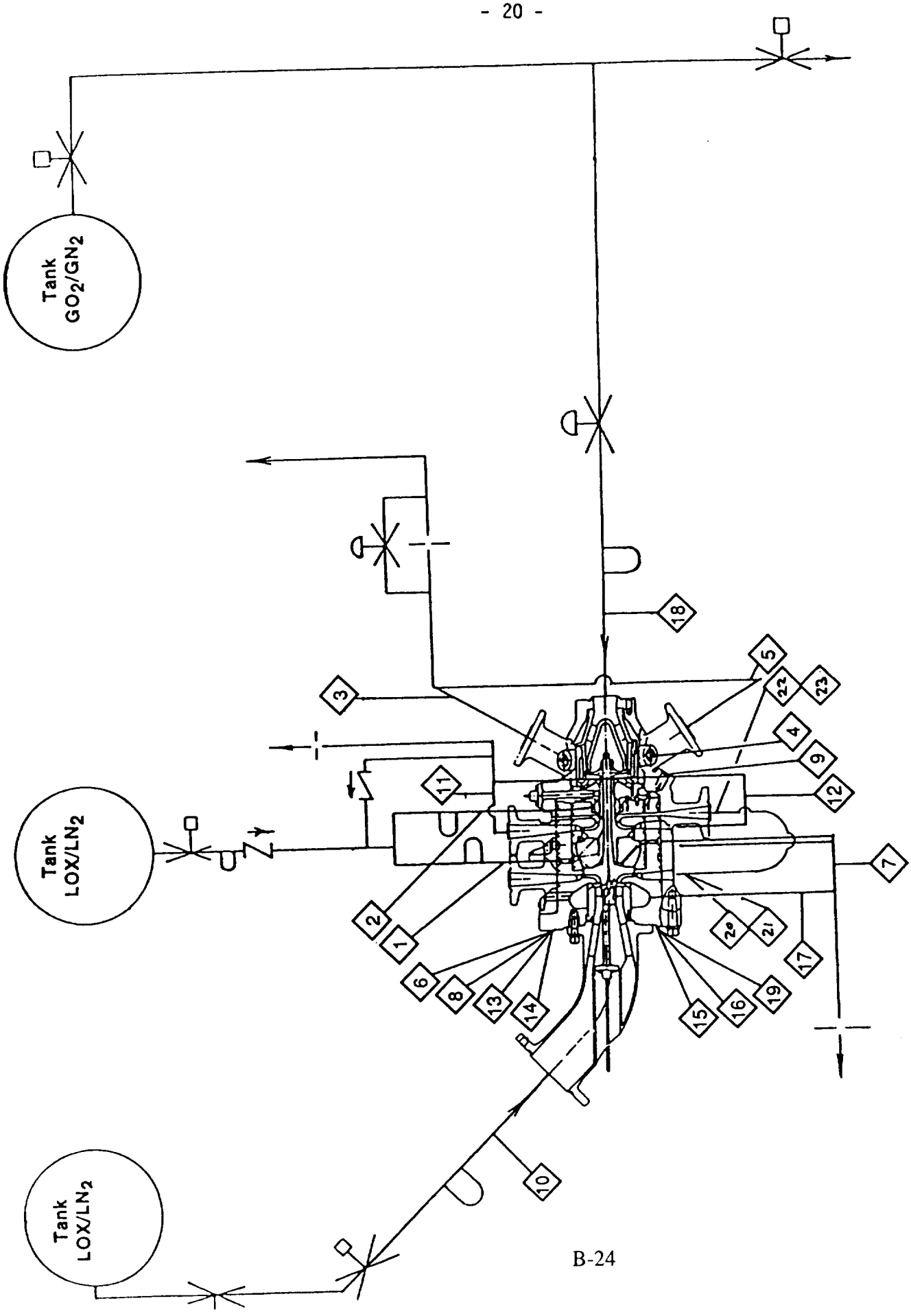


Figure 8.2-2. Instrumentation Locations — Transducer Channels

SYMBOL AND NO.	FUNCTION	TPA PORT NOMENCLATURE & LOCATION (INCH,DEGREES)	TEST LAB INSTRUMENT NOMENCLATURE	TYPE	UNITS & RANGE
1	TURBINE END ACCELERATION, VERTICAL	(6.86,0)	GTX	ACCELEROMETER	0 TO 15G, 2HZ TO 7KHZ
2	TURBINE END ACCELERATION, HORIZONTAL	(6.86,270)	GTY	ACCELEROMETER	0 TO 15G, 2HZ TO 7KHZ
3	PUMP END ACCELERATION, AXIAL	(-0.56,180)	GPZ	ACCELEROMETER	0 TO 15G, 2HZ TO 7KHZ
4	PUMP END ACCELERATION, VERTICAL	(0.81,0)	GPX	ACCELEROMETER	0 TO 15G, 2HZ TO 7KHZ
5	PUMP END ACCELERATION, HORIZONTAL	(0.81,270)	GPY	ACCELEROMETER	0 TO 15G, 2HZ TO 7KHZ

TABLE 8.2-3. INSTRUMENTATION LIST - HIGH FREQUENCY CHANNELS

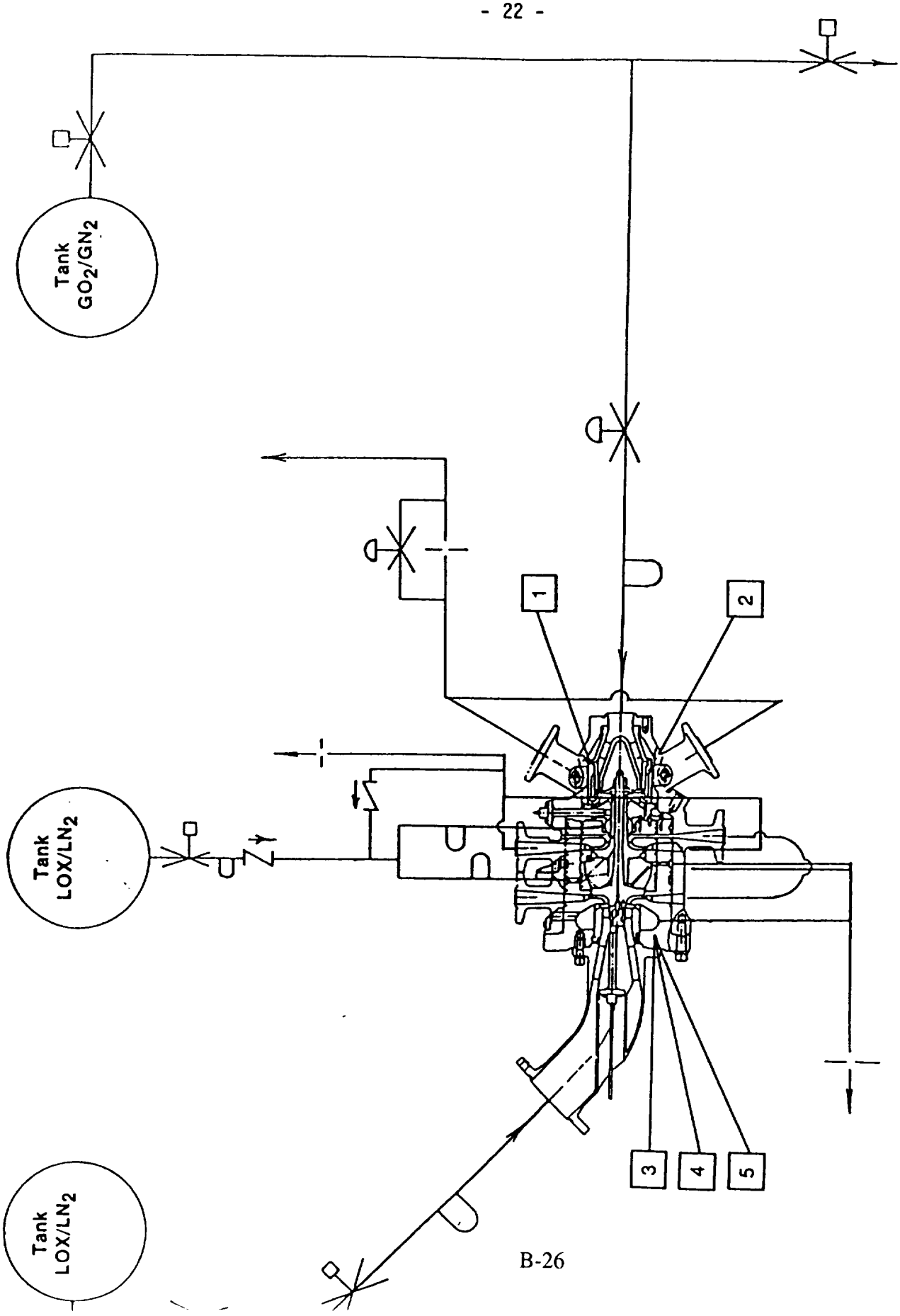


Figure 8.2-3. Instrumentation Locations — High Frequency Channels

SYMBOL AND NO.	FUNCTION	TPA PORT NOMENCLATURE & LOCATION (INCH,DEGREES)	TEST LAB INSTRUMENT NOMENCLATURE	TYPE	UNITS & RANGE
1	TURBINE INLET MASS FLOW		WTI	MICROMOTION	0 TO 7 LBM/SEC
2	TURBINE EXHUAST MASS FLOW		WTE	MICROMOTION	0 TO 7 LBM/SEC
3 *	DISTANCE DETECTOR, RADIAL	(4.08, 120)	DDTX	PROBE	0 TO 24 VOLTS
4 *	DISTANCE DETECTOR, RADIAL	(4.08, 210)	DDTY	PROBE	0 TO 24 VOLTS
5 *	DISTANCE DETECTOR, AXIAL	(-1.23, C'LINE)	DDTZ	PROBE	0 TO 24 VOLTS
6 **	SHAFT SPEED, RADIAL	(4.08, 120)	NT-X	PROBE	0 TO 80,000 RPM
7 **	SHAFT SPEED, RADIAL	(4.08, 210)	NT-Y	PROBE	0 TO 80,000 RPM
8 **	SHAFT SPEED, AXIAL	(-1.23, C'LINE)	NT-Z	PROBE	0 TO 80,000 RPM

* OUTPUT TO BE DISPLAYED ON OSCILLOSCOPE REAL TIME

** CHANNEL TO BE DISPLAYED REAL TIME

TABLE 8.2-4. INSTRUMENTATION LIST - SPECIALTY CHANNELS

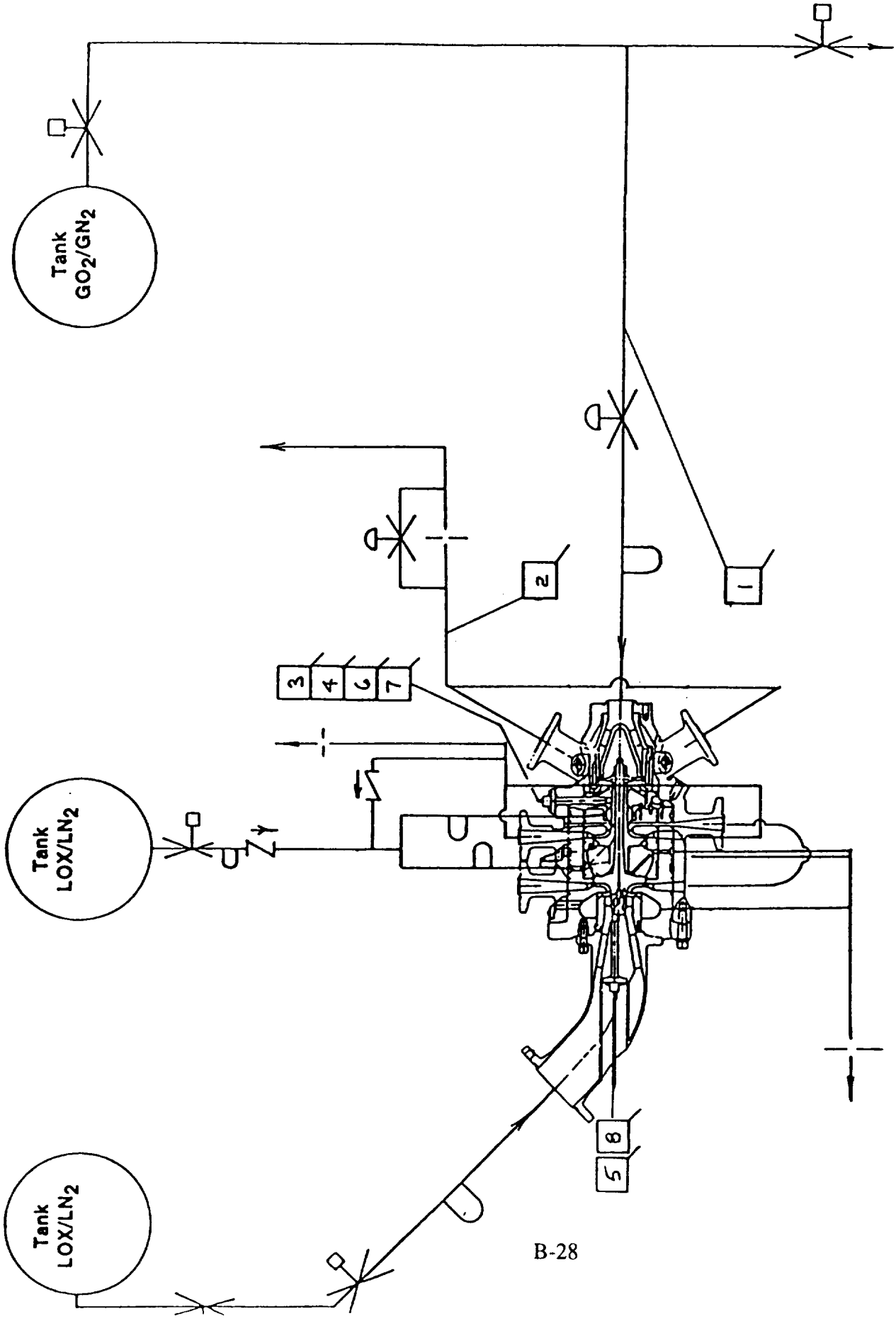


Figure 8.2-4. Instrumentation Locations — Special Channels

8.3 Oscilloscopes

Two oscilloscopes are required. One scope shall display the two radial displacement probes in x-y format. The axial displacement probe shall be displayed on the second scope on a time base.

8.4 Audio-Visual

At least one video camera shall be used to transmit a real time image of the turbopump and its installation to the control room. At least one microphone shall be used in the test cell to transmit audio information about the health of the turbopump to the control room during testing.

9.0 Data Requirements

The data to be furnished by the WSTF Test Organization for each test performed falls into four general categories. These are digital data, floppy diskettes, magnetic tape and video record. The requirements are described in the following sections. The Test Organization shall retain archive copies of all test data for a minimum of 3 years.

9.1 Digital Data

Digital printed data shall be provided for all test runs for quick look purposes, in absolute engineering units (e.g.; psia, ^{o}R). This data shall be in the form of a time history for the test. It is permissible to use an "edit ratio" in printing the data scans, for selected tests, to reduce the volume of printed data. The edit ratio shall be coordinated with the cognizant Aerojet Project Engineer. It is anticipated that the digital data will be computer printouts. One copy of all digital data shall be furnished to the Project Engineer.

9.2 Floppy Diskettes

All data shall be furnished to Aerojet Engineering on floppy diskettes in spread sheet format. This data will be calibrated, but not screened or reduced.

9.3 Magnetic Tape

Output signals from accelerometers and distance detector probes shall be continuously recorded on magnetic tape. One copy of all magnetic tape data shall be stored at the appropriate archive for three years. Timecode corresponding to digitally recorded data shall also be recorded on the magnetic tape.

9.4 Video Record

At least one video camera shall be focused on the turbopump and operating during testing and a video tape record shall be made and archived.

10. Photographic Records

The Test Facility shall provide 8" x 10" color photographs documenting the test stand with the test unit installed. These shall include both overall views and detailed close-up views. The photographs shall be sufficient in quantity and detail to identify plumbing and instrumentation line connections before insulation is applied. Additional photographs shall be taken before and during the test program as required by either Aerojet or WSTF engineers to document exact construction details or significant changes in the installation.

WSTF shall provide photos of the oscilloscope screen showing probe traces for each test sequence.

APPENDIX C

Task Order B.8 Revised Schematic and Schedule

GENCORP AEROJET

Aerojet TechSystems
P O Box 13222
Sacramento CA 95813-6000

bcc: DFVronay, File

5 October 1989
9001:DAB043:hmw

NASA/Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. Albert A. Spence

Subject: Contract NAS3-23772, Orbit Transfer Rocket Engine Technology Program, Task B.8

Reference: (a) NASA/LeRC Letter 5320, dated 13 September 1989

Dear Mr. Spence:

The following are being sent to you per your request in Reference (a):

Enclosure (1) supercedes Figure 1 of current Work Plan for Task B.8. It represents the most recent OTV Engine Schematic.

Enclosure (2) is a revised schedule reflecting details of OTPA refurbishment and extended pretest support effort due to slip of CER from October 1989 to March 1990. Please note that this slip extends current test schedule beyond task's current period of performance.

Very truly yours,

DAB

Debra A. Blagg
Contract Manager

Enclosures: (1) Revised Cycle Schematic for Dual Expander Engine
(2) Revised Schedule for Hot GOX Testing at WSTF

cc: G. Paul Richter, Program Manager, NASA/LeRC
Margaret P. Proctor, Task Order Manager, NASA/LeRC

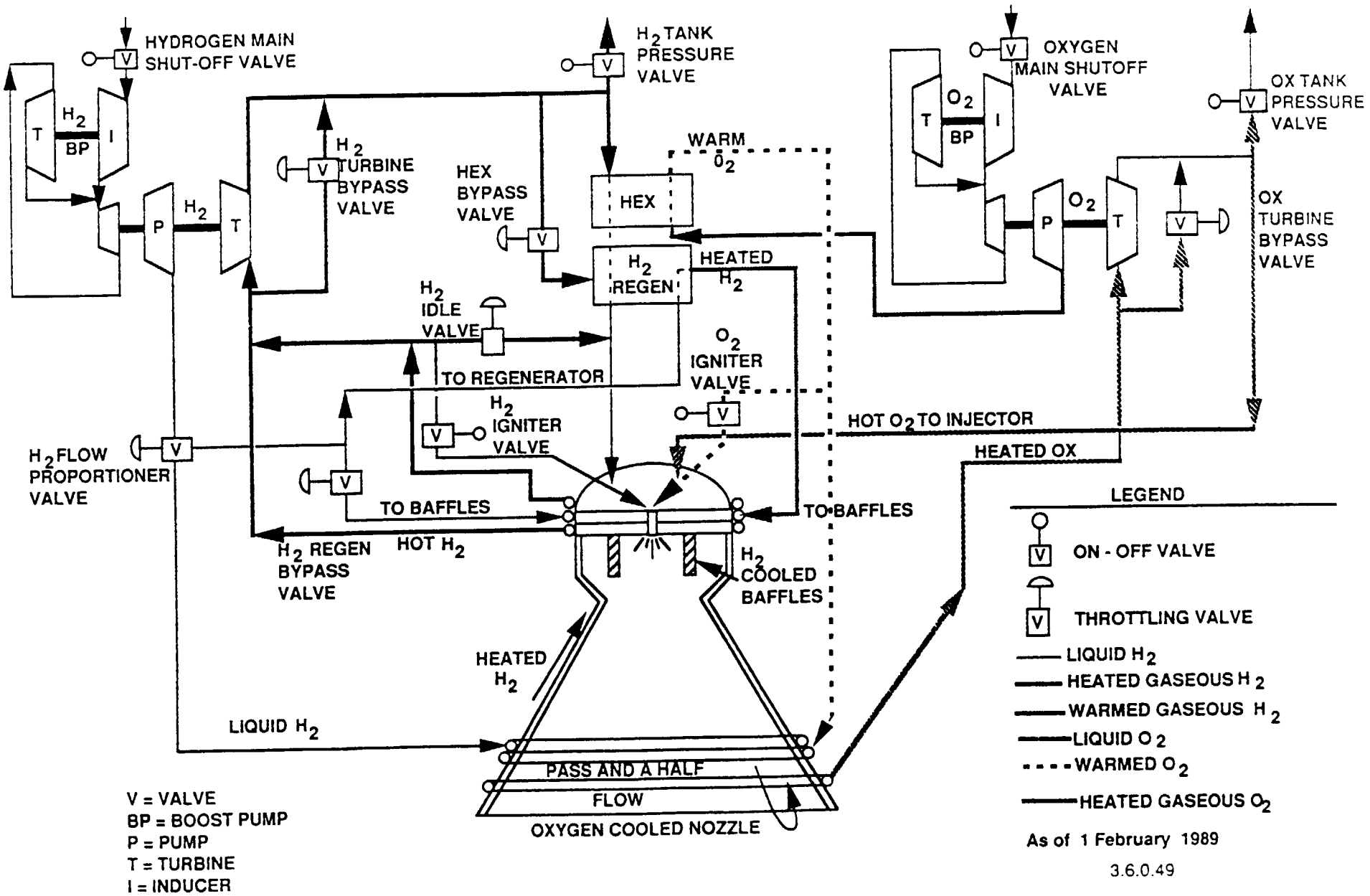


Figure 1. Dual Expander Cycle Schematic (Updated Version)

OTV OTPA SERIES F TESTING
TASK B.8

CONTRACT 3 NAS3-23772

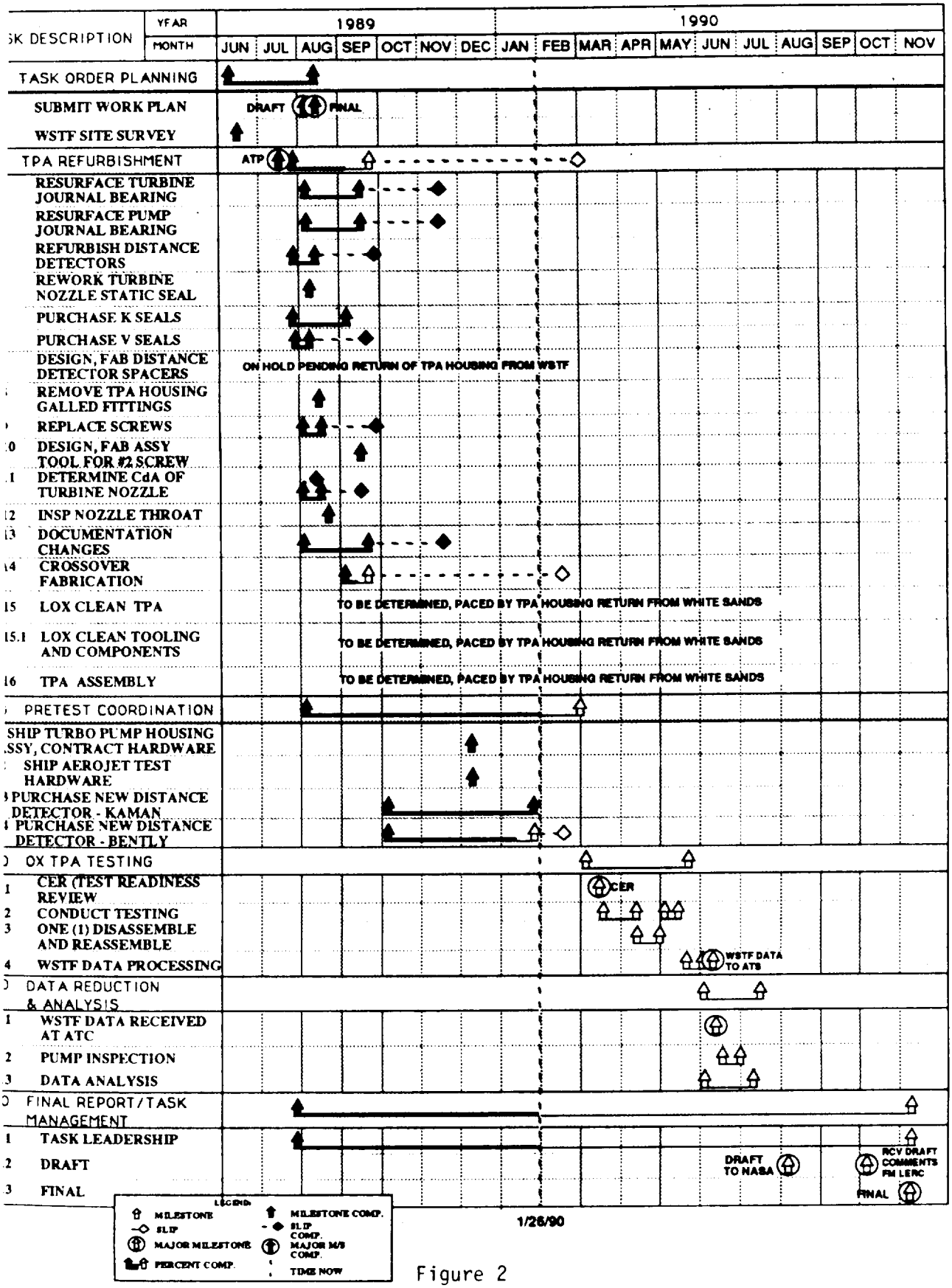


Figure 2

APPENDIX D

Task Order B.8 OTPA Testing at WSTF

GENCORP
AEROJET

Aerojet TechSystems
P O Box 13222
Sacramento CA 95813-6000

22 December 1989
9001:DAB095:hmw

bcc: DFVronay, WHayden, RBrannan,
TPetersen (Letter only),
File (With photos) 3.2 & 4.2

NASA/Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. G. Paul Richter/Ms. Margaret Proctor

Subject: Contract NAS3-23772, Task B.8; OTPA Testing at WSTF

Dear Paul/Margaret:

Per WSTF request, enclosed are six (6) detailed photographs of the OTPA test setup used at Aerojet for Series C.D and E Testing. Additionally, enclosed is a photograph of the bailment hardware. The bailment hardware was shipped from Aerojet to WSTF on 21 December 1989. Finally, a copy of a video tape showing typical Bently Probe Orbits is being sent to WSTF, along with the original photographs.

Please contact Dennis Vronay at (916) 355-5021, if you have any questions.

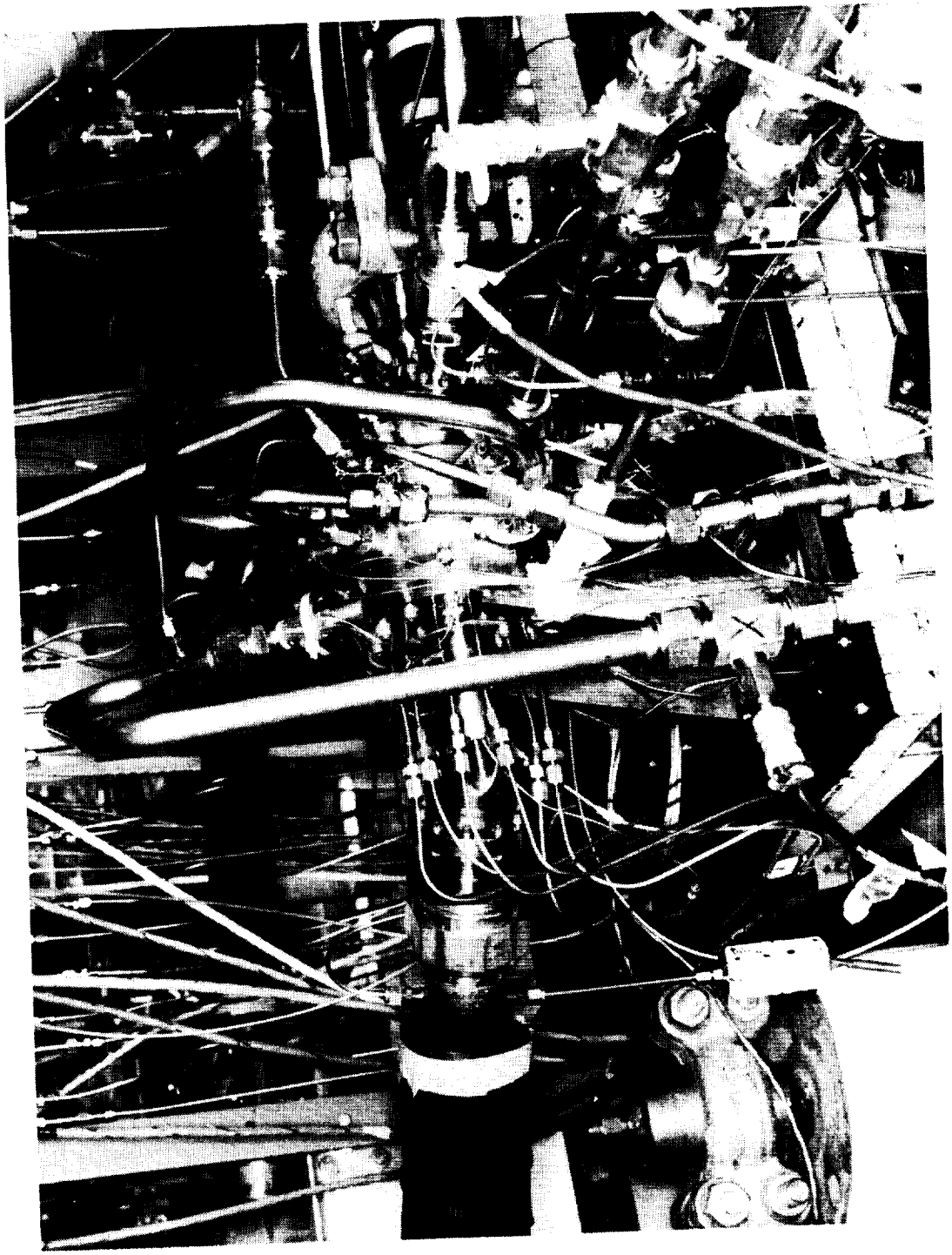
Very truly yours,

Debra A. Blagg
Contract Manager

Enclosures: Seven (7) Photographs

Photo ID	
C0389-1027	OTV Test Series C-2, Test Setup
C0389-1028	" "
C0389-1029	" "
C0389-1030	" "
C0389-1031	" "
C0389-1032	" "
C0989-5692	Bailment Hardware (Numbered)

cc: D. Baker/WSTF (With Original Photographs and Video Tape)



(C0389 1027)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

(C0389 1028)

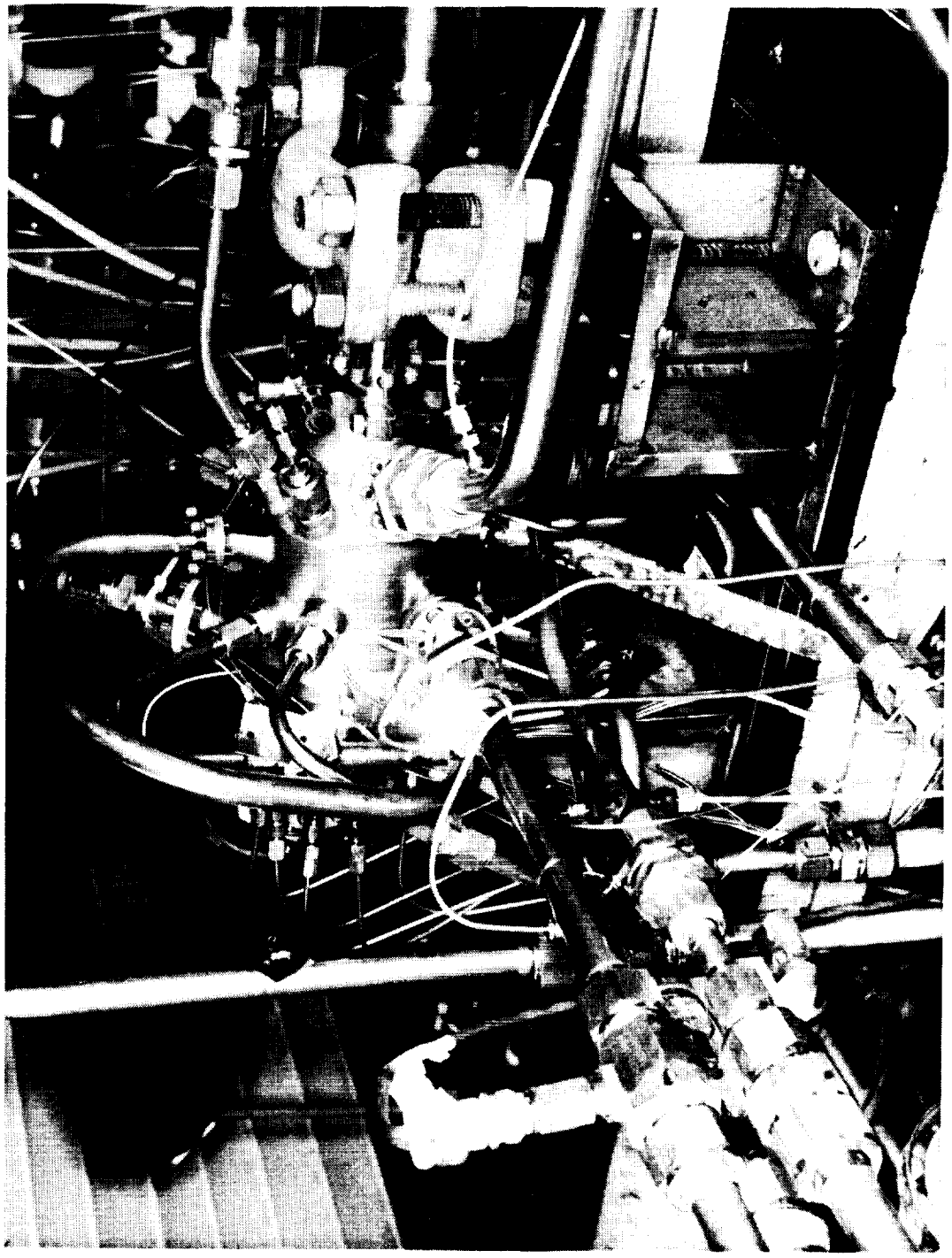
OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

(C0389 1029)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



(C0389 1030)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

(C0389 1031)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

(C0389 1032)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

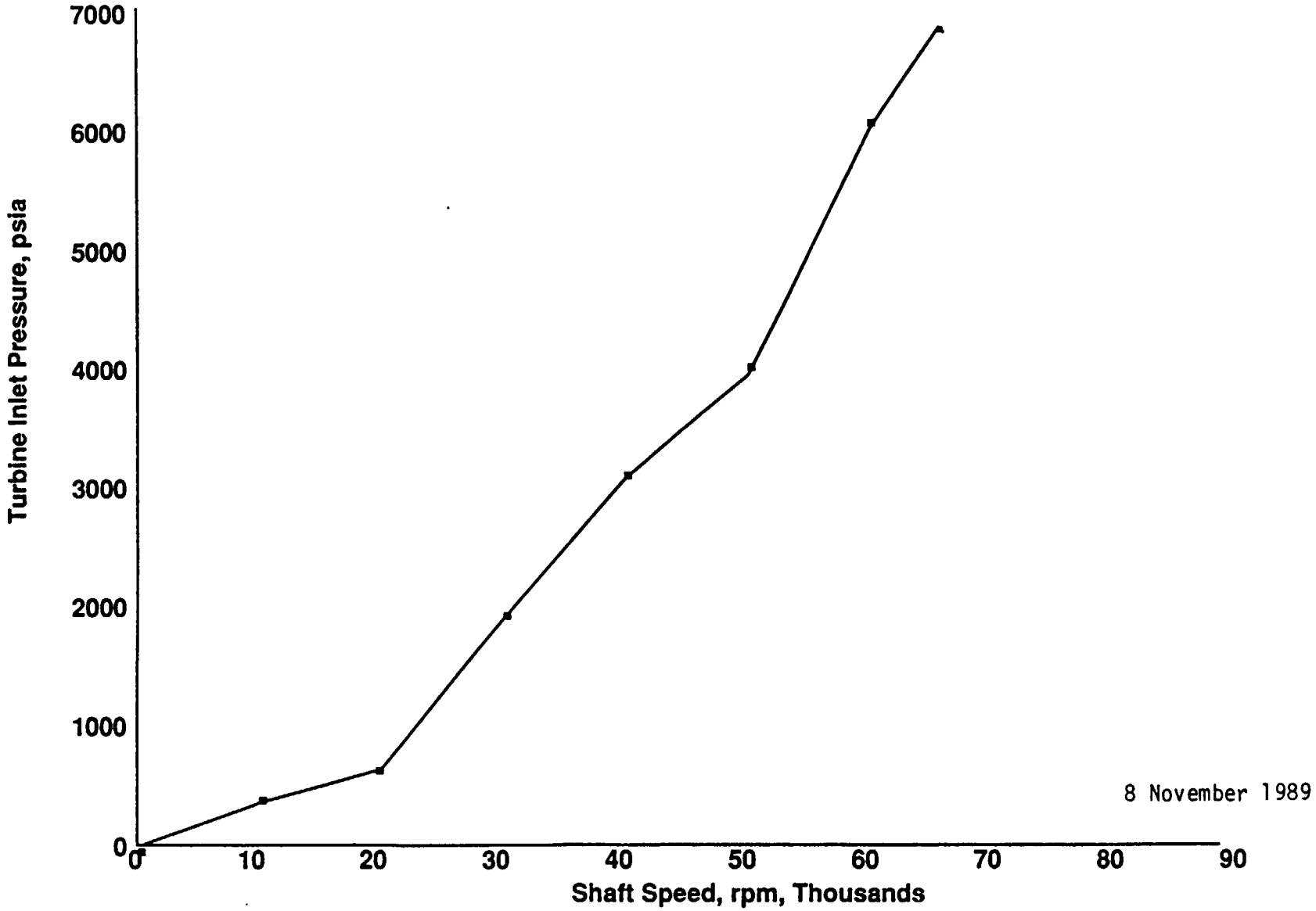
(C0989 5692)

OTV - OTPA Test Series, C-2 Test Setup

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

GenCorp
Aerojet
TechSystems

OTV Engine Liquid Oxygen Turbopump



M10/dD14/VG-1

GenCorp
Aerojet

TechSystems

FACSIMILE COVERSHEET

P.O. Box 13222, Sacramento, California 95813 (916) 355-1000

TO: MR. DAVE BAKER

FAX NO.: (505) 524-5260

PAGE 1 of 2

TELEPHONE: (505) 524-5604

COMPANY: WHITE SANDS TEST FACILITY

XEROX 295 FAX:916/355-5470 Voice Verification: 916/355-6903

ORIGINATOR: DEBRA A. BLAGG
Bldg 2001/Dept 9001

PHONE: 916/355-2705

DATE: 11/8/89

I certify that this document does not contain any classified or company information that needs protection.

SIGNATURE Debra Blagg

REMARKS

Per your request,

Warren Hayden

GenCorp
Aerojet

TechSystems

FACSIMILE COVERSHEET

P.O. Box 13222, Sacramento, California 95813 (916) 355-1000

TO: MS. MARGARET PROCTOR	FAX NO.: (216) 433-2629 or 5489	PAGE
TELEPHONE: (216) 433-2430		1 of 2
COMPANY: NASA/LEWIS RESEARCH CENTER		

XEROX 295 FAX:916/355-5470 Voice Verification: 916/355-6903

ORIGINATOR:	DEBRA A. BLAGG Bldg 2001/Dept 9001	PHONE: 916/355-2705	DATE: 11/8/89

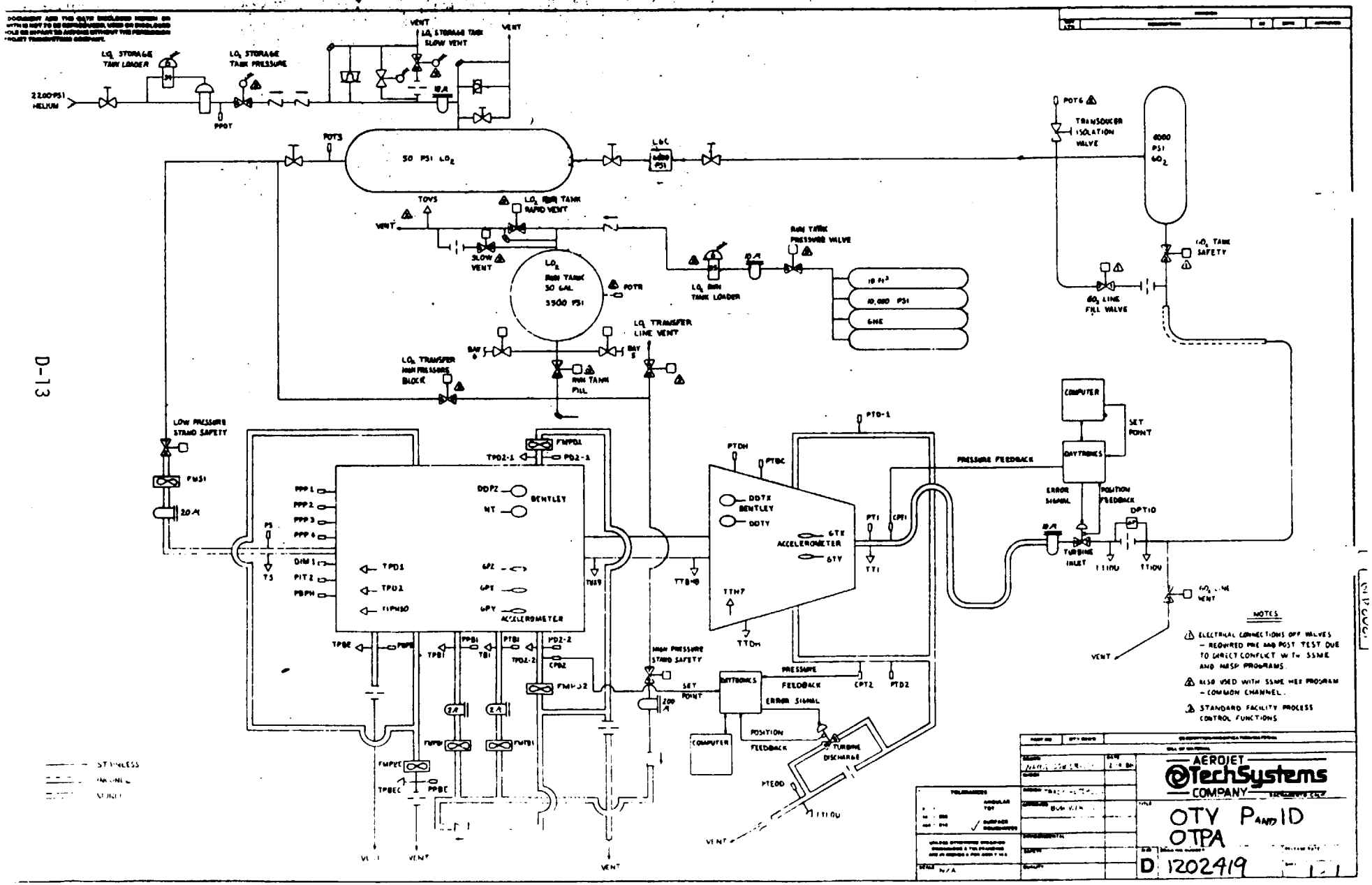
I certify that this document does not contain any classified or company information that needs protection.

SIGNATURE Debra Blagg

REMARKS

Per your request,

Warren Hayden


2200 PSI HELIUM
PPOT
LO2 STORAGE TANK LOADER
LO2 STORAGE TANK PRESSURE
VENT
LO2 STORAGE TANK SLOW VENT
POT3
50 PSI LO2
LOC
TOVS
LO2 RUN TANK RAPID VENT
SLOW VENT
LO2 RUN TANK 50 GAL 3500 PSI
POT8
LO2 RUN TANK LOADER
RUN TANK PRESSURE VALVE
LO2 TRANSFER LINE VENT
LO2 TRANSFER MAIN PRESSURE BLOCK
RUN TANK FILL
POT6
TRANSDUCER ISOLATION VALVE
6000 PSI GO2
LO2 TANK SAFETY
GO2 LINE FILL VALVE
LOW PRESSURE STAND SAFETY
FMS1
20 A
PPP1
PPP2
PPP3
PPP4
DIM 1
PITZ
PBPH
TPD1
TPD2
FIPH30
DDPZ
BENTLEY
NT
6PZ
6PX
6PY
ACCELEROMETER
PS
TS
TMS9
FMPD1
TPD2-1
PD2-1
PTDH
PTBC
DDTX
BENTLEY
DDTY
6TX
ACCELEROMETER
6TY
PTI
CPI
TTH7
TTDH
TTB-8
PTD-1
COMPUTER
SET POINT
DAYTRONICS
PRESSURE FEEDBACK
ERROR SIGNAL
POSITION FEEDBACK
DPT10
TURBINE INLET
T111OU
T11OU
GO2 LINE VENT
VENT
NOTES
1. ELECTRICAL CONNECTIONS OFF VALVES - REQUIRED PRE AND POST TEST DUE TO DIRECT CONFLICT W T= SSME AND NASP PROGRAMS.
2. ALSO USED WITH SSME HEX PROGRAM - COMMON CHANNEL.
3. STANDARD FACILITY PROCESS CONTROL FUNCTIONS
PPBI
PTBI
PD2-2
TPD2-2
CPB2
FMPD2
TPBE
PPBE
TPBI
TBI
FMPD1
FMPD2
TPBEC
PPBEC
HIGH PRESSURE STAND SAFETY
SET POINT
200 A
DAYTRONICS
PRESSURE FEEDBACK
ERROR SIGNAL
CPT2
PTD2
COMPUTER
POSITION FEEDBACK
TURBINE DISCHARGE
PTE0D
T111OU
VENT
STAINLESS
AEROJET TechSystems COMPANY
OTV P AND ID
OTPA
D 1202419

GENCORP
AEROJET TechSystems

FACSIMILE COVERSHEET

P.O. Box 13222, Sacramento, California 95813 (916) 355-1000

TO: MR. JIM DANNIELS	FAX #	PAGE
TELEPHONE: -5604	505-524-5260	1 of 2
COMPANY: WHITE SANDS TEST FACILITY		

FROM: Xerox FAX: 916/ 355-5470	Voice Verification: 916/ 355-6903

ORIGINATOR	PHONE	DATE
WARREN HAYDEN	916-355-3643	10/30/89

I certify that this document does not contain any classified or company information that needs protection.	SIGNATURE

REMARKS

THIS IS THE AEROJET FACILITY SCHEMATIC. IF THE DETAILS ARE TOO SMALL TO READ WE WILL MAIL A FULL SIZED DRAWING ON YOUR REQUEST.

APPENDIX E

Review of WSTF Test Facility Schematic

AEROJET TECHSYSTEM
Interoffice Memorandum

01 Febraury 1990
9512:5318:TVP:mtg

TO: D. F. Vronay

FROM: T. V. Petersen

SUBJECT: White Sands Test Facility Preliminary LOX Turbopump Fluid Schematic

After reviewing the preliminary sketch of the WSTF test set-up, I have noted the omission of some details needed for an accurate sketch. These details are as follows:

1. Location of the turbine inlet Micro-Motion mass flow measurement device.

2. Turbine discharge line size.

3. Capacity of bearing supply tank.

4. Materials of construction (stainless steel vs. monel).

5. Location of turbopump purge system.

In addition, some characteristics of the test stand not usually included on a facility drawing may enlighten Aerojet personnel with regard to the expected functioning of the test stand. These are:

1. Turbine inlet line capacitance downstream of BX540 (turbine shut-off valve).

2. The actuation time and sequence of operation for turbine inlet valves BX540-542.

3. Physical allowances made for thermal expansion loads on the turbine inlet.

4. Intended purpose of orifice BX549.

5. Expected size of orifice BX551.

6. Chill-in procedure for pump discharge circuits (orifice bypass may be required).

7. Surface area of bearing inlet filters.

8. Total length - insulated and uninsulated - of the pump suction line.

9. Flow capacity of suction line filter.

Tracy Petersen

T. V. Petersen
Test Engineer
Test Research and
Development Laboratories
Test Operations

Approved by:

A K. Dalgleish

C.c- E. M. VanderWall
Manager, A-Zone
Test Operations